Industrial QUALITY CONTROL

VOL. V NOVEMBER, 1948 NO. 3

Part of Clinic 2B conducted by Colonel Leslie E. Simon at the First Annual Regional Quality Control Clinic, Philadelphia and Delaware Sections, ASQC. (See page 5)

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REPORT OF PHILADELPHIA CLINIC

Edward B. Haden

The First Annual Regional Quality Control Clinic in the Philadelphia area was held on Friday, September 17th. The Clinic was sponsored jointly by the Philadelphia and Delaware sections of ASQC, and the Management Service Division of Temple University. It drew an attendance of approximately 250 people of management status from the surrounding industries. Sixteen well known manufacturers exhibited the latest type of gage equipment and other tools used in statistical quality control.

The clinic program was built around the general theme "The Economics of Quality Control," and was focused on two main divisions: the Chemical Industry and the Mechanical Industry. In the morning Dr. Martin A. Brumbaugh of Bristol Laboratories explained the use of statistical quality control in the laboratory and in the production of penicillin. At the same time Mr. O. P. Beckwith of Alexander Smith & Sons Carpet Company illustrated how statistical quality control in the laboratory and in production aids the textile industry.

The luncheon speaker was Ralph Wareham, president of ASQC. He spoke on "Industrial Cost-Quality Relationship." The early afternoon clinic sessions were conducted by Dr. Grant Wernimont of the Eastman Kodak Company, and Colonel Leslie E. Simon, Director of the Ballistic Research Laboratory in Aberdeen, Maryland. Following these two presentations, Mr. William L. Gore of E. I. duPont deNemours Company explained the practicability of statistical sampling methods in the chemistry field, and Mr. Joseph E. Manuele of the Westinghouse Electric Corporation illustrated how quality control functions in production processes.

At the dinner session Professor Irwin S. Hoffer of Temple University was presented with a silver dish appropriately inscribed in recognition of his fine work in furthering the advancement of statistical quality control in this area. The dish was presented jointly by the Philadelphia and Delaware sections. After this presentation ceremony, Mr. Harrison F. Dunning, General Manager of Scott Paper Company, completed the day's program by discussing "The Economics of Quality Control From a Management Point of View."

The interest created by this Clinic encourages the belief that such programs are mutually beneficial to the sponsors and the industrial community they serve.

Tolerances— Additive or Pythagorean?

F. S. ACTON AND **E. G. OLDS**

CARNEGIE INSTITUTE OF TECHNOLOGY

When statistical concepts first enter an engineering field they frequently bring a new set of definitions and ideas which conflict with established practices. Familiar terms are used for unfamiliar ideas, and the impression frequently is given that the new methods are in direct contradiction to the old, whereas quite often they are merely desirable refinements achieved from a different viewpoint.

TWO KINDS OF TOLERANCE

In designing machined parts for interchangeable assembly, the total tolerance for the assembled units must be broken down into manufacturing tolerances for the individual pieces. Established practice in many shops seems to decree that the sum of the individual tolerances shall equal the total tolerance, if the assembly consists of several items placed end to end so that their dimensions add. The simplest example of this is the Johannson gage block. Here the lengths of the individuals are added to get the total length, and the tendency is to add the tolerances in the same way. On the other hand many statistical articles imply that the correct procedure is to add the **squares** of the tolerances to get the **square** of the total tolerance, and therefore the total tolerance is the square root of the sum of the squares of the tolerances. This is the way to get the hypotenuse of a right triangle, or the principal diagonal of a rectangular box, so perhaps a good descriptive term for the rule would be **Pythagorean**. (Note that we are not, at the moment, concerned with the other common tolerance problem, where it is a question of setting tolerances so as to insure clearance between male and female parts such as pistons and cylinders. This problem, though similar, is treated later.)

Which, then, is correct? Should tolerances be considered as additive or Pythagorean? The confusion arises because there are at least two kinds of tolerances in common use, and they are rarely distinguished in discussions of tolerance problems. Being unaware of any better convention, we shall hereafter refer to:

1. **Absolute tolerances**—by which we mean that **no item** shall exceed these limits, and
2. **Natural tolerances**—by which we mean that very few, but still a definite percentage, of the items may, on the average, exceed these limits.*

If we examine the output of some machine cutting off rods of, say, 2 inches length, and if we plot a frequency distribution of the lengths actually cut off, the distribution may look like one of those pictured in Figure 1. Let us consider the advantages of the two kinds of tolerances in discussing distributions of these types.

The absolute tolerance defined above has meaning only when applied to finite distributions, such as the rectangular and doubly truncated normal; it is the same thing as what might be called the **range** of these distributions. The normal distribution, however, has no such limits; hence there can be no absolute tolerances connected with any dimension which we have reason to believe is normally distributed. This is a rather severe limitation on the usefulness of absolute tolerances, especially when one realizes that many shop operations, when in statistical control, often give stable distributions that are nearly normal.

The natural tolerance, on the other hand, has meaning for **any** distribution. It is usually taken as 6σ where σ is the standard deviation of the distribution. For some work it may be more convenient to define it as 8σ or 4σ, but it is always defined as $2k\sigma$, where k is a constant. Most tolerances in common engineering use today are wide natural tolerances, but they are usually treated as if they were absolute tolerances.

COMBINING NATURAL TOLERANCES

Natural tolerances are Pythagorean. That is, for n parts added together the natural tolerance T on the total length is given by the formula

$$T^2_n = t^2_1 + t^2_2 + \ldots + t^2_n$$

where t_1 is the natural tolerance of the first piece, etc. The great advantage gained by using natural tolerances is that the percentage of the assemblies which will exceed the total natural tolerance may usually be computed accurately and without much difficulty. Sample calculations are given in this paper. This can be done because of a theorem in mathematical statistics which shows that the distribution of the sum of n variables of almost any form tends rapidly toward a normal distribution as n is increased, and the probabilities for the normal case are given in tables.

Just how rapidly the normal is approached depends, of course, on the initial distributions. If one of the distributions has a much larger

*These tolerance limits should be distinguished from the distribution-free tolerance limits treated by Wilks and Wald in several papers in the *Annals of Mathematical Statistics*: *12* (1941) pp. 91-96; *13* (1942) pp. 400-409; *14* (1943) pp. 45-49.

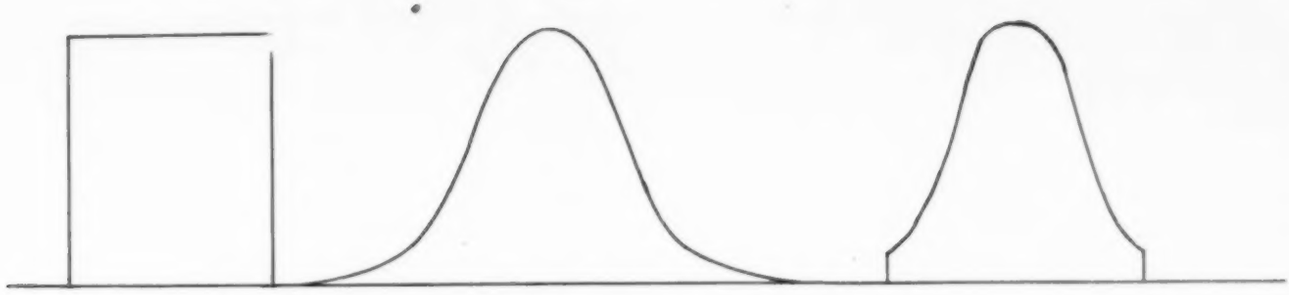


FIGURE 1—TYPES OF DISTRIBUTION

variance than the others, then it tends to dominate the form of the distribution of the sum. Thus if this dominant distribution is far from normal (say rectangular) the approach to normality will be impracticably slow. Fortunately, in practice, the parts which are added in a single assembly tend to have comparable variances, so this difficulty is rather infrequent. If the original distributions have a single hump somewhere near the middle, their sum will approach normality faster than, say, the sum of rectangulars. But even with the rectangular distribution, a sum of four of comparable range is already close enough to normality to warrant using the normal tables for probabilities. If the distribution turns out to be as bad as a rectangular one (a rare case), the probabilities can be computed exactly, although these computations are not easy unless the ranges are nearly the same for all n components.

In summary: for the sum of four or more components, regardless of the form of the individual distributions, it seems satisfactory to regard the distribution as normal, and to apply tables of the normal integral in estimating the percentage outside of natural tolerances. For the sum of two or three components which are normally or rectangularly distributed, the percentages can be obtained exactly. Most distributions met in practice differ from the normal less than does the rectangular. Therefore the deviation from normal of their sum is less than the deviation of the sum of an equal number of rectangulars, and hence the percentage outside of natural tolerances in the case of the rectangularly distributed variables can serve as a lower limit to that usually met in industry.

THE TROUBLE WITH ABSOLUTE TOLERANCES

Absolute tolerances are additive. They are the tolerances that engineers have been using, and using correctly in the sense that since no individual item exceeds its absolute tolerance, then the total length of n items never exceeds the total absolute tolerance. The difficulties with this absolute tolerance are, however, threefold:

(a) Many naturally occurring distributions are nearly normal; that is, they have a small but real probability of exceeding any tolerance that a design engineer may want to designate as an absolute tolerance. In such cases absolute tolerances are not realistic.

(b) In practice, a rectangular or other finite distribution like the truncated normal has the best chance to occur from 100% tolerance inspection of a machine's output, with an **infallible** inspector rejecting all pieces outside the absolute tolerance. If the inspector has been infallible, the distribution certainly does cut off sharply, and an absolute tolerance has meaning. In every case which has come to the authors' attention, however, some outside-of-tolerance pieces have passed the inspector, so that the actual distribution did, in fact, have "tails" beyond the tolerance limits. Thus, even a few items missed by an inspector may invalidate the concept of an absolute tolerance and its subsequent usefulness.

(c) Even if one manages to obtain a real absolute tolerance on the components, the resulting total absolute tolerance is wasteful in assembly because of the improbability of several extremely large pieces being selected for the same assembly. That is, practically all of the assemblies will run **well within** the total absolute tolerance, and hence the tolerances are stricter than is necessary for proper functioning of the assembly. If enforced, the absolute tolerance wastes material at the machines, raises costs by demanding unnecessary precision, and usually requires excessive inspection. If unenforced, it demoralizes the shop personnel, who quickly lose respect for all tolerances and the ability of the engineers to set them. The inevitable sequel is that shop personnel begin to substitute individual judgments for the proper tolerances—a procedure which leads to uncontrolled quality of the product.

It is possible to express the absolute tolerance of the truncated normal, or any finite distribution, as a constant times the standard deviation and thus as a constant times the natural tolerance. This allows the use of the absolute tolerance in some probability calculations, a procedure which is of questionable value if there are more than two components. It is mentioned here simply to warn the reader that all tolerances which appear to have been squared and added are not necessarily natural ones, but may be absolute tolerances which have been modified. As this modification is confusing in

the literature, we feel it should be discouraged. An exception is the rectangular distribution, where the range of the distribution is a natural parameter and is also the absolute tolerance. Any discussion of natural tolerances for the rectangular, therefore, will usually be formulated in terms of this range.

EXAMPLE

To illustrate some of the previous remarks, let us assume we are engaged in manufacturing three gears for assembly on the same shaft, the gears being held on one side by an enlargement of the shaft, and on the other by a bearing housing. The assembly is shown in Figure 2. If the widths, x_1, x_2, x_3, of gears 1, 2, and 3 are all normally distributed as manufactured, and have the values shown in Table 1, then we must compute the natural tolerance on S, the sum of the three dry gear widths. All dimensions are in inches.

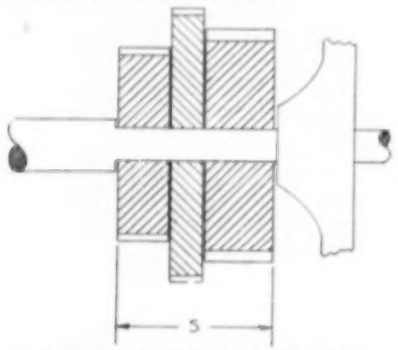


FIGURE 2—GEAR ASSEMBLY

The value of

$$\bar{S} = \bar{x}_1 + \bar{x}_2 + \bar{x}_3 = 1.5000,$$

$$\sigma_S = \sqrt{(.0010)^2 + (.0009)^2 + (.0015)^2} = .00200,$$

and

$$T_n = 6\sigma_s = 0.0120.$$

T_n may also be computed directly from the t_n's by the Pythagorean rule. Since the distributions of the three gear widths were assumed to be normal, the distribution of their sum is also normal, and we can use the table of areas under the normal curve to compute the probability of an assembly exceeding the natural tolerance of 0.0120 inches. Our definition, quite arbitrary, was that $T_n = 6\sigma_s$. Looking in a table of the normal integral such as is found in most statistics texts*, we see that the area included between zero and 3σ is 0.49865. Thus 0.00135 is the area in the right hand tail of the distribution. Since our limits are $\pm 3\sigma$, and since the curve is symmetric, the total area excluded by our tolerances is 2(.00135) = 0.00270. Remembering that the total area under the normal curve is 1.0000, we see that 0.27% is not included between the tolerance limits. This means that a random assembly from these gears will yield an outside-of-tolerance assembly about three times in one thousand, on the average. The reason we are able to make this statement is that we have assumed that the gears are being produced in the shop with widths that are normally distributed with the means and standard deviations shown in Table 1. In order that this assumption be something more than a pious hope, it is necessary that sufficient sampling inspection be performed in the shop to keep control charts. Any speculation about probabilities of being within tolerances of **any** kind is nonsense unless one can be sure that the distributions of the dimensions are stable—i.e. **controlled.**

*Freeman, H. A., *Industrial Statistics*, p. 166, Table IV.

TABLE 1

Gear	average width $= \bar{x}$	σ_x	$t_n = 6\sigma_x$
1	0.5000	0.0010	0.0060
2	0.3000	0.0009	0.0054
3	0.7000	0.0015	0.0090

TRUNCATING THE NORMAL CURVE

When the natural tolerance for the total width of the assembled gears has been calculated, we may find that it exceeds the specifications. If the natural tolerances of the components cannot be reduced by process changes, it may be necessary to reduce their variability by 100% inspection. In that case the Pythagorean formula cannot be used for the assembly tolerance until the standard deviations of the new (tail-less) distributions have been calculated.

Two sample calculations are given below, the first being the symmetrical case where the normal distribtuion with a mean of zero has been truncated at $x_T = \pm k\sigma$; the second being non-symmetrical truncation. In addition to these calculations, two graphs are presented which dispense with the necessity of performing the symmetrical calculations. (Note that the abscisses are not plotted on the same scales.) Graphs for the non-symmetric case could also be constructed, and would be distinctly worth while if one had to make many of these computations. Graphs 1 and 2 are included in this paper because all normal truncation problems require the use of a table of the incomplete second moment of the normal distribution. This is Table IX of Karl Pearson's **Tables for Statisticians and Biometricians, Volume I,** which volume, unfortunately, is not as generally available as might be desired.

Case I. A normal distribution with mean 0.7000 and standard deviation 0.0015 is to be truncated at 0.6967 and 0.7033; that is, at $x_T = \pm 0.0033$, or at $x_T = \pm(2.2)\sigma$. Find the standard deviation of the truncated distribution.

For a distribution, truncated at distances of $\pm\, k\sigma$ from the mean, the standard deviation, σ_c (in σ-units) is obtained from the relation,

$$\sigma_c^2 = \frac{\int_{-k}^{k} u^2 f(u)\,du}{\int_{-k}^{k} f(u)\,du}$$

where

$$f(u) = \frac{1}{\sqrt{2\pi}}\, e^{-\frac{u^2}{2}}.$$

Since both the original and truncated distributions are symmetric,

$$\sigma_c^2 = \frac{2\int_0^k u^2 f(u)\,du}{2\int_0^k f(u)\,du} = \frac{\int_0^k u^2 f(u)\,du}{\int_0^k f(u)\,du}.$$

In this last expression, the denominator is the area under the normal curve from 0 to $x_T = k\sigma$, and its value can be found in any set of statistical tables. (For example, Table II in Pearson.) In our problem it is 0.4860966. (This, and other entries from Pearson's **Tables**, are given in full in order to facilitate checking by anyone interested.) The numerator is the entry found in Pearson's Table IX, under

the heading m_2, and is the number 0.4080525. Thus

$\sigma_c^2 = (0.4080525)/(0.4860966)$
$= 0.839$

and

$\sigma_C = 0.916$.

Since this is the standard deviation achieved by truncating a normal curve of **unit** standard deviation, it is also the ratio σ_T/σ for our particular distribution. Thus

$\sigma_T = 0.916\sigma = 0.00138$,

since $\sigma = 0.0015$. This same value for σ_T can be obtained via Graph 1, by entering with $x/\sigma = 2.2$. From the graph we also see that about 2.8% of the product was apparently removed by the previous 100% inspection, if, indeed, that was the source of the truncation. This result can also be obtained from our calculations by noting that 0.5000 $-$ 0.4861 $=$ 0.0139 $=$ fraction of area in **each** tail. Thus the total area excluded by the truncation is 0.0278 or 2.8%.

Case II. If the distribution had been cut at 0.6967 and 0.7927, i.e. at $x_1 = -0.0033 = -2.2\sigma$ and $x_2 = 0.0027 = 1.8\sigma$, then

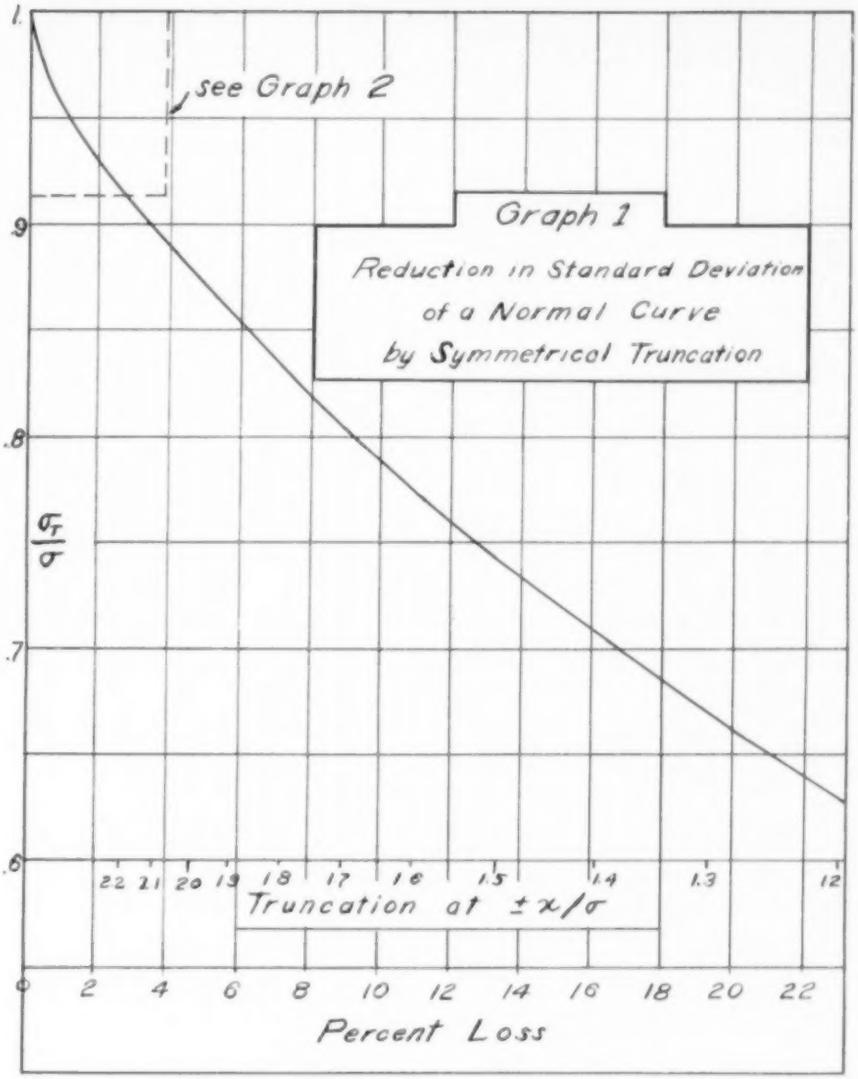
$$\sigma_c^2 = \frac{\int_{k_1}^{k_2} u^2 f(u)\,du}{\int_{k_1}^{k_2} f(u)\,du} - \left[\frac{\int_{k_1}^{k_2} u f(u)\,du}{\int_{k_1}^{k_2} f(u)\,du}\right]^2$$

$$\sigma_c^2 = \frac{\int_{k_1}^{0} u^2 f(u)\,du + \int_{0}^{k_2} u^2 f(u)\,du}{\int_{k_1}^{0} f(u)\,du + \int_{0}^{k_2} f(u)\,du} - \left[\frac{\int_{k_1}^{0} u f(u)\,du + \int_{0}^{k_2} u f(u)\,du}{\int_{k_1}^{0} f(u)\,du + \int_{0}^{k_2} f(u)\,du}\right]^2.$$

The numerators of the first fraction are taken from the m_2 column of Pearson's Table IX, the denominators of both fractions from normal area tables. The numerators of the second fraction are found in the m_1 column of Pearson's tables, and care must be taken to note that the first integral will usually be negative because the function tabulated is

$$\frac{1}{\sqrt{2\pi}} \int_0^x u\, e^{-\frac{u^2}{2}}\, du$$

where x is a **positive** number. Thus



$$\sigma_c^2 = \frac{0.4080525 + 0.3219594}{0.4860966 + 0.4640697} - \left[\frac{-0.3634677 + 0.3199921}{0.4860966 + 0.4640697}\right]^2$$

$$= 0.7683.$$

The correction term is subtracted because, by definition, the variance is the average squared deviation about the **mean** of a distribution. The first fraction gives the average squared deviation about the mean of the **untruncated** distribution, and so the second fraction is the squared deviation of the mean of the truncated distribution from the mean of the original one.

Anyone familiar with moments of inertia will recognize the first fraction to be the moment about some arbitrary line in a homogeneous plate with the correction term converting this fraction into the moment about a line through the center of gravity of the plate. The correction term is not present when the truncation is symmetrical, as the mean of the new distribution then coincides with the old. By the same logic, if the truncation is not severely asymmetric, this term will be small.

Although the standard deviations of non-symmetrically trun-

cated distributions can generally be computed in this way, it should be remembered that the sum of two or three variables which are all distributed in the same lopsided manner is not normally distributed. Thus it is difficult to compute exact probabilities if the truncation has been severely one sided, as might happen if only oversized measurements were screened out and the undersized ones left.

If we now assume that all three gears have been inspected so that, for their distributions,

$$\sigma_{T_1} = 0.00095,$$
$$\sigma_{T_2} = 0.00086,$$
$$\sigma_{T_3} = 0.00138$$

(by truncation at $x_T = \pm 2.46\sigma_1$, $\pm 2.50\sigma_2$, and $\pm 2.20\sigma_3$ respectively), then we shall compute the standard deviation of the total dimension, S, exactly as before

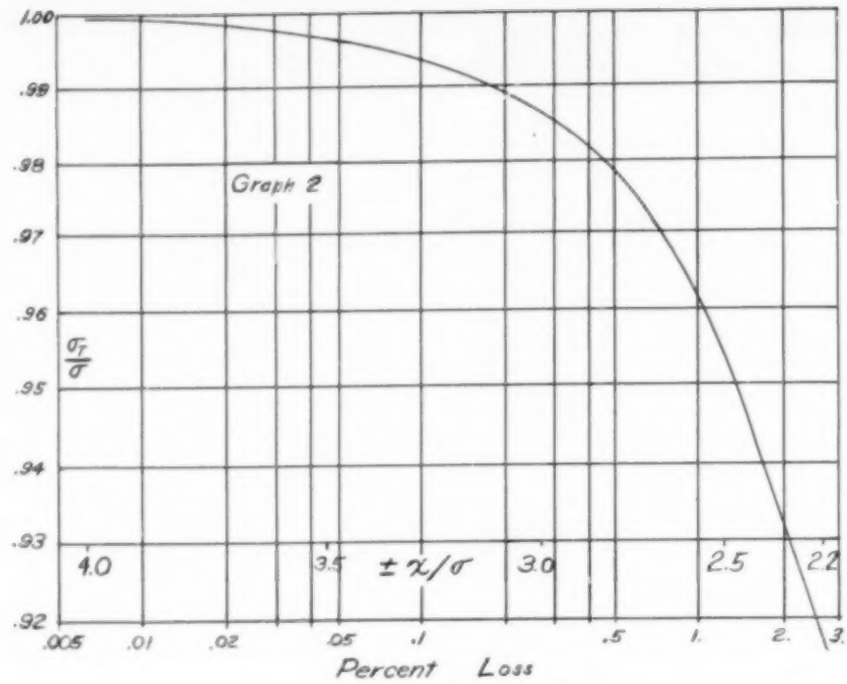
$$\sigma_S = \sqrt{(.0095)^2 + (.00086)^2 + (.00138)^2}$$
$$= 0.00188.$$

The sum, S, may be treated as though normally distributed with $\bar{S} = 1.5000$ and with $\sigma_s = 0.00188$. This approximation (due to the truncation) is conservative in the sense that less than the expected 3 in 1000 assemblies should fall outside the 6σ limits, i.e. outside of 1.4944 and 1.5056. On the other hand, the inspectors are certainly not infallible, so, in fact, the truncation is not perfect and the actual standard deviations of the components are slightly larger than we have computed. This pushes the probabilities in the wrong direction, which tends to make the normal table a good bet.

RECTANGULAR APPROXIMATIONS

If a normal distribution is severely cut down (by truncation at $x_1 = \pm 0.50\sigma$, for example), the remainder resembles a rectangular distribution. This suggests that a useful approximation to the resultant natural tolerance for the assembly of components so truncated can be obtained by considering the addition of rectangular distributions.

Let us, therefore, now assume that the three components are all rectangularly distributed as shown in Table 2, instead of normally as



before. R is the range, or absolute tolerance. R and σ_x are connected by the equation $R = 2\sqrt{3}\sigma_x$.

In this example the distributions have been chosen so that t_n is the same as in the previous example. Thus $\bar{S} = 1.500$ and $T_n = 0.0120$. The range, or absolute tolerance, is the sum of the ranges, or 0.0118; nearly the same as T_n. This agreement is peculiar to three components, as a glance at Figure 3 will show. Figure 3 compares graphically the absolute tolerance for the sum of n identically rectangularly distributed pieces with the natural tolerance for the same assembly. Both tolerances are plotted in units equal to the range of an individual item. For the special case we are studying, the choice between absolute and natural tolerances matters little, as they are identical for $n = 3$ and close for $n = 2$ or $n = 4$. (The apparent discrepancy between the two tolerances in the example is due to rounding off of some numbers in the calculations).

We now see why the engineering practice of using absolute tolerances has considerable justification for rectangularly distributed variables when two or three components are being used. It is, nevertheless, a rather limited justification.

As the probabilities of exceeding any specified limits on S may be computed exactly for this case, it is interesting to compare the exact result with the probabilities obtained by using the normal curve. Exact computations, which are quite complicated, show that the limits of 1.4949 to 1.5051 (a natural tolerance of 0.0102) will be exceeded about **three** times in 1000, while the normal curve predicts ($\pm 2.55\sigma$) **eleven** times in 1000. At a natural tolerance of 0.0118, the exact prediction is **zero** (since this is an absolute tolerance and hence none should exceed it) while the normal curve says **three.** When we consider that the normal curve is not recommended for a sum of less than four rectangularly distributed pieces, the agreement is not too bad.

MALE-FEMALE FITS

There remains the case for the assembly of two parts in a male-female fit. Whereas the previous problems have been concerned

TABLE 2

Gear	$\bar{x}$	R	σ_x	$t_n = 6\sigma_x$
1	0.5000	.0035	.0010	.0060
2	0.3000	.0031	.0009	.0054
3	0.7000	.0052	.0015	.0090

with the tolerance of the **sum** of several lengths, we now consider the tolerance of the **difference** between two lengths. Natural tolerances are well behaved in this case; they are still Pythagorean. The clearance will be the difference between the female and male dimensions, and the natural tolerance of this clearance will be given by the formula

$$T_n = \sqrt{t^2_1 + t^2_2}.$$

If the diameter, x, of a bolt is normally distributed with mean $\bar{x} = 0.345$ and $\sigma_x = 0.0015$, and if the hole diameter, X, is normally distributed with mean $\bar{X} = 0.354$ and $\sigma_X = 0.0020$, then the clearance, C, is normally distributed with $\bar{C} = \bar{X} - \bar{x} = 0.009$ and

$$\sigma^2_c = (.0015)^2 + (.0020)^2 = (.0025)^2.$$

Thus $\sigma_c = 0.0025$, and the natural tolerance of $6\sigma_c$ is 0.0150. The clearance will fall below some practical limit (say 0.003, which is $\frac{.009 - .003}{.0025} = 2.4\sigma$) in about 0.82% of all random assemblies of bolts and holes. The probability of a "too loose" fit could also be calculated if the definition of such a fit were given. If the probabilities of these improper fits are too great, then the bolts or holes can be 100% inspected, thus truncating the distributions. The reduced standard deviations of the truncated distributions can be calculated exactly as in the earlier example. The final tolerances on the new clearance will be computed as above, but using the new reduced natural tolerances.

Absolute tolerances on the two parts are added, as before, to give the absolute tolerances for the clearance. They are also subject to the same disadvantages as previously.

SUMMARY

In summary, we have:

1. Defined "natural tolerances" as $2k\sigma$ where k is an arbitrary constant;
2. Distinguished between the properties of absolute and natural tolerances, showing the advantages of the latter;
3. Given sample calculations for the natural tolerance of an additive assembly;

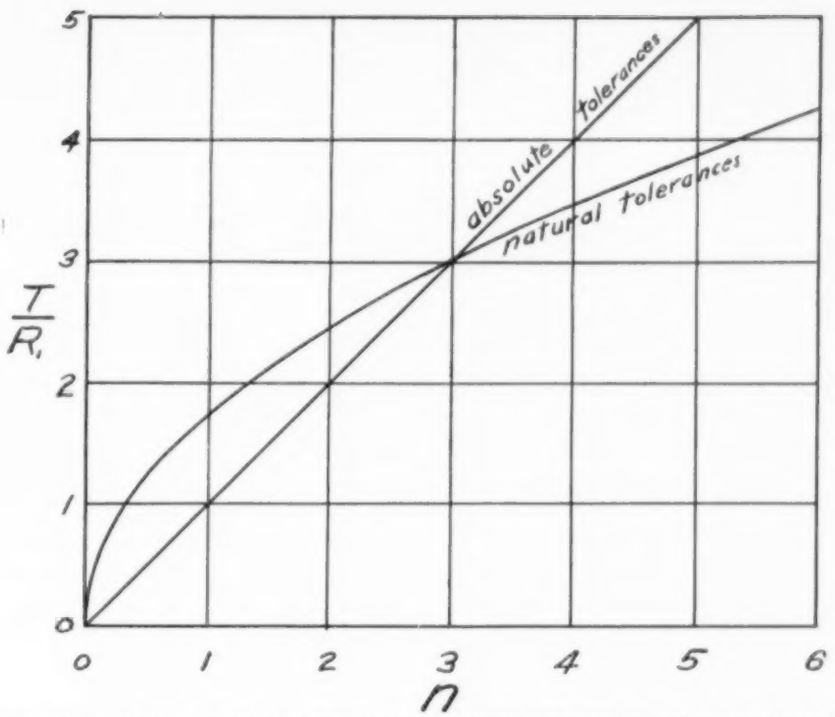


FIGURE 3—COMPARISION OF NATURAL WITH ABSOLUTE TOLERANCE FOR AN ASSEMBLY OF n RECTANGULARLY DISTRIBUTED COMPONENTS

4. Given sample computations for the standard deviation of a truncated normal distribution when the untruncated is known;
5. Pointed out the fact that a male-female tolerance problem can be handled in exactly the same manner as the additive case if we use natural tolerances and consider the clearance to have a natural tolerance.

In a future paper we hope to discuss, with perhaps more detail, some of the calculations involved in deciding whether to truncate, change process, or selectively fit when a random assembly will not meet specifications. We will not give pat answers to this problem, as too many economic variables are unknown to make realistic calculations, but typical sample calculations for the statistical parts of the problem will be attempted. Because the rule of combination of natural tolerances is Pythagorean, it is fairly obvious that, if we are out of tolerance in an assembly, we should attempt to reduce the variability of the component having the largest standard deviation. A reduction in any of the others would have a relatively small effect.

Two further points remain. As stated earlier, the choice of 6σ for the natural tolerance is purely arbitrary. We could have used, say, 6.58σ or 7.46σ instead. To these three definitions correspond three statements about the normally distributed gear assembly:

(1) Approximately 3 assemblies out of 1000 will not lie between 1.4940 and 1.5060.

(2) Approximately 1 assembly out of 1000 will not lie between 1.4934 and 1.5066.

(3) Approximately 1 assembly out of 5000 will not lie between 1.4925 and 1.5075.

These statements are self-consistent, and the one to be used for discussion will be largely a matter of taste. Adherence to a single level of probability, however, will lessen the chance for confusion.

A final remark concerns the probabilities that natural tolerances will be exceeded. In the cases of normal and rectangular distributions the probabilities are exact. In the case of the truncated normal, computations suggest that the probabilities lie between those for the rectangular and the normal

for values of the variables usually occuring in tolerance problems. For extremely skewed distributions, one takes one's chances, but here we feel that a close look at the process may disclose a correctable defect which gives rise to the peculiar shape of the distribution, a defect whose correction will enable not only reliable tolerances but **closer** tolerances to be held.

Administration of a Sampling Inspection Plan*

HAROLD F. DODGE
BELL TELEPHONE LABORATORIES

PURPOSE

The purpose of this discussion is to outline some of the problems associated with the administration of a sampling inspection plan for a product of individual articles. The principles are much the same whether we are dealing with single sampling, double sampling, multiple sampling, or sequential sampling.

EXPERIMENT

Bowl of 200 chips, representing a lot of 200 parts; 34 red (defective), remainder white (nondefective).

One person acts as inspector, mixes chips thoroughly, draws a sample of 10, finds 1 defective; returns sample to bowl; nine others do the same: mix chips, draw a sample of 10; results vary, some finding 0 defectives, others 1, 2, 3, etc. defectives.

If one is asked "From your sample, what do you judge to be the percent defective in the lot?" he might reply, "0%, 10%, 20%, etc.," according to the findings in his sample. The findings differ. From the experiment certain conclusions can be drawn.

(a) The sample drawn by the inspector is just one of an unlimited number of samples, a universe of like-drawn samples.

(b) With thorough mixing, or with random samples, any one sample is as good as any other.

(c) The sample percent defective is by no means necessarily the same as the lot percent defective. (Impossible in this case for samples of 10, where the lot was 17% defective.)

(d) In routine inspections, the sample is not drawn for the purpose of estimating lot quality. (There is little hope for close estimates in most inspections because $p'n$ is usually small; p' = lot fraction defective, n = sample size.)

(e) Rather, the sample results provide a basis for **action**: accept the lot, reject the lot, take a second sample, etc. (For the single sampling plan: $n = 10$, $c = 0$; accept if no defectives are found in the sample, reject if 1 or more are found.)

TWO PURPOSES OF INSPECTION

Inspection serves two purposes*:

(a) To provide a basis for action on the **product** as it comes to the inspector: accept, reject (or rework);

(b) To provide a basis for action on the **process** in the interests of future product: leave the process alone or correct the process.

The first purpose is immediate, and has as its objective a curative procedure, to patch up ailing product; the second purpose is long range, and has as its objective a preventive procedure, to assure good health in tomorrow's product.

ONE HUNDRED PERCENT INSPECTION

In 100% inspection, individual articles are rated as either good or not good, accepted or rejected. The total results of such inspection **can** be used for both purposes mentioned above but too often are used only for the first.

One hundred percent inspection is often necessary, as for critical features for which no defects can knowingly be tolerated. A simple functional test or check of each article is warranted for many products. But 100% inspection does not mean complete freedom from defects, since the inspection operation is not perfect; inspection fatigue and margins of error in testing equipment come into play.

For many characteristics, a goal of perfection is quite uneconomical. If defects are not critical, 1 defective in 1,000, or 1 in 100 may not only be good enough but truly economic. If we can tolerate some defectives, as we must, then we can sample. How many we can stand is the problem.

For some characteristics, there is no alternative to sampling, as when tests are destructive, and also for physical properties of materials, characteristics of extrusion products, bulk materials, fluids, etc.

*Presented at the Training Conference on Acceptance Sampling, Newark College of Engineering — October, 1946.

*REF. 1, p. 1.

One trouble with 100% inspection, where it is practicable, is that the inspector merely cleans up the faults of others, sorting the good from the bad, and the production man takes it as a matter of course if just individual articles are returned to him for repair. But if a whole lot is returned to him, as when lot sampling is used, and he is required to undertake the entire corrective action, the steady outward flow of product is interrupted. If there are many lot rejections, he must get busy to find the cause and eliminate it in order to avoid further lot rejections. This is an indirect power of sampling—it forces correction of the process, where the fault lies.

TYPES OF INSPECTON IN A MANUFACTURING PLANT

It is convenient to classify inspections in a manufacturing plant as follows:

(a) **Receiving inspection:** inspection of raw and semi-fabricated materials, parts, components, etc., purchased from outside suppliers or furnished by other departments in the same company.

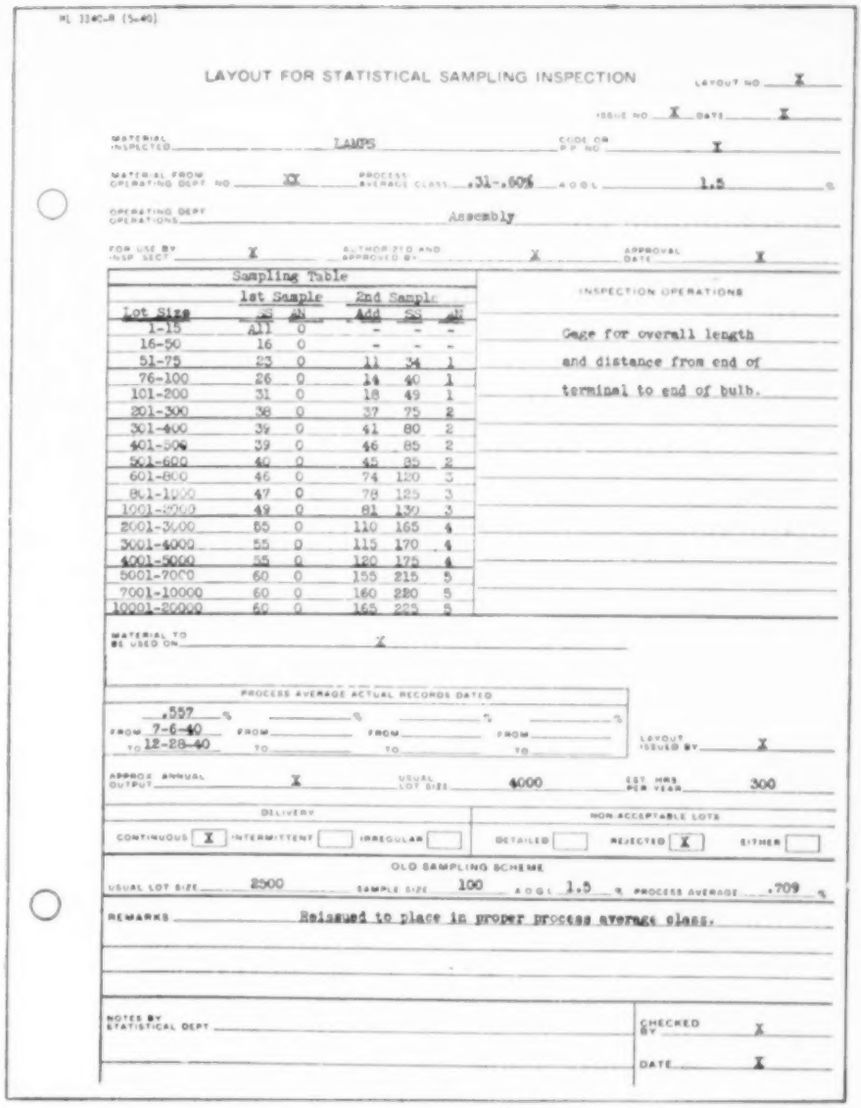
(b) **Process inspection:** inspection of parts, partial assemblies, etc., between, during, and after operations; interdepartmental and intradepartmental.

(c) **Final inspection:** inspection of finished articles or products; 100% for some products or characteristics, sampling for others.

(d) **Check inspection:** sampling inspection of a small quantity of finished product, packaged or not, ready for shipment to customer (for over-all quality determination).

Much inspection effort is concentrated in process and final inspections. What is wanted is an economical standard of quality at all stages.

Continuous production in the idealized sense is the exception rather than the rule. Varieties of product types commonly introduce some discontinuities but there is commonly a fair degree of repetition in most quantity production.



LAYOUT FOR STATISTICAL SAMPLING INSPECTION

LAYOUT NO. X

ISSUE NO. X DATE X

MATERIAL INSPECTED: LAMPS — CODE OR P.P. NO. X

MATERIAL FROM OPERATING DEPT. NO. XX — PROCESS AVERAGE CLASS .31-.60% — AOQL 1.5 %

OPERATING DEPT OPERATIONS: Assembly

FOR USE BY INSP. SECT. X — AUTHORIZED AND APPROVED BY X — APPROVAL DATE X

Sampling Table

Lot Size	1st Sample n	Ac	2nd Sample Add n	Ac	Re
1-15	All	0	-	-	-
16-50	16	0	-	-	-
51-75	23	0	11	34	1
76-100	26	0	14	40	1
101-200	31	0	18	49	1
201-300	38	0	37	75	2
301-400	39	0	41	80	2
401-500	39	0	46	85	2
501-600	40	0	45	85	2
601-800	46	0	74	120	3
801-1000	47	0	78	125	3
1001-2000	49	0	81	130	3
2001-3000	85	0	110	165	4
3001-4000	55	0	115	170	4
4001-5000	55	0	120	175	4
5001-7000	60	0	155	215	5
7001-10000	60	0	160	220	5
10001-20000	60	0	165	225	5

INSPECTION OPERATIONS

Gage for overall length and distance from end of terminal to end of bulb.

MATERIAL TO BE USED ON: X

PROCESS AVERAGE ACTUAL RECORDS DATED

.557 % FROM 7-6-40 TO 12-28-40 — % FROM TO — % FROM TO — % FROM TO

LAYOUT ISSUED BY X

APPROX ANNUAL OUTPUT X — USUAL LOT SIZE 4000 — EST HRS PER YEAR 300

DELIVERY: CONTINUOUS [X] INTERMITTENT [ ] IRREGULAR [ ]

NON-ACCEPTABLE LOTS: DETAILED [ ] REJECTED [X] EITHER [ ]

OLD SAMPLING SCHEME

USUAL LOT SIZE 2500 — SAMPLE SIZE 100 — AOQL 1.5 % — PROCESS AVERAGE .709 %

REMARKS: Reissued to place in proper process average class.

NOTES BY STATISTICAL DEPT.

CHECKED BY X

DATE X

FIGURE 1 — FORM FOR INSPECTION LAYOUT

Reproduced from "Sampling Inspection Tables" Dodge and Romig, John Wiley & Sons

INSTALLATION OF A SAMPLING PLAN

How would one proceed to set up a sampling plan, say, an AOQL plan? Let us take a simple but typical case in a manufacturing plant, namely, the inspection of a component part or a simple subassembly, now inspected 100%. To get under way, we must get some information on what kind of quality we are dealing with.

First, make a complete list of characteristics for which inspection is made:

(a) Dimensions — subject to gaging,

(b) Characteristics — subject to test, electrical, mechanical, etc., and

(c) Visual defects — of assembly, finish, workmanship, condition.

Second, make up a form for tabulating the number of defects of each kind observed in 100% inspection (can be used for analyzing past inspection results if detailed records have been kept). Suppose only dimensions and visual defects are involved. On the form tabulate each dimension to be gaged, using a separate line for each dimension —two lines if both maximum and minimum limits are specified. On

the form leave a line for recording each kind of visual defect encountered, each to be described very specifically — including such things as damaged threads, incomplete threads, burrs on base-end, excess tool marks on pinion, cracks, dents, grease. Use a wide form with 25 to 50 or more columns, to permit comparison of results over an extended period of time. If inspected by lots, use a separate column for each lot; if not broken down into lots, use a separate column for the results of each hour, each half-day, or each day.

Third, analyze the results of the 100% inspection, for a total of 10 to 25 lots or periods. In each column, list the number of each kind of defect found. Observe what defects repeatedly occur. This shows where the weak spots are. Discuss results with operating foreman, urging action to reduce prominent defects.

Fourth, if some defects are excessive, study other defects by groups according to inspection operations. Commonly when sampling cannot be introduced for all characteristics collectively, it can be introduced for some, such as an individual dimension or a group of dimensions subject to gaging by one inspector. Compute percent defective for each such characteristic or group, to determine past process average percent defective (100 $\bar{p}$). Consider one such group; make an estimate of the allowable percent defective, considering the relative cost of 100% inspection for this group, and the cost of trouble in subsequent operations if defects go through to the next assembly stage.

(a) If $\bar{p}$ is 5% to 6%, and only 1% can be tolerated, continue 100% inspection; keep the record going, tabulating the results column by column (plot a chart if possible), send a copy to each operating foreman, with credit to the foreman as defects are reduced.

(b) If $\bar{p}$ — 1% or less and 1% can be tolerated, use a 1% AOQL sampling plan.

Fifth, follow this procedure for the several characteristics, individually or in groups, with close cooperation of inspection and production groups. Visual defects are usually observed in one operation (sometimes in two), hence usually comprise one group. Objective: to reduce defects of all kinds to such a level of percent defective that all may be treated as one group and one AOQL sampling plan used for all defects collectively; a critical dimension may be an exception, hence it may be continued on 100% inspection.

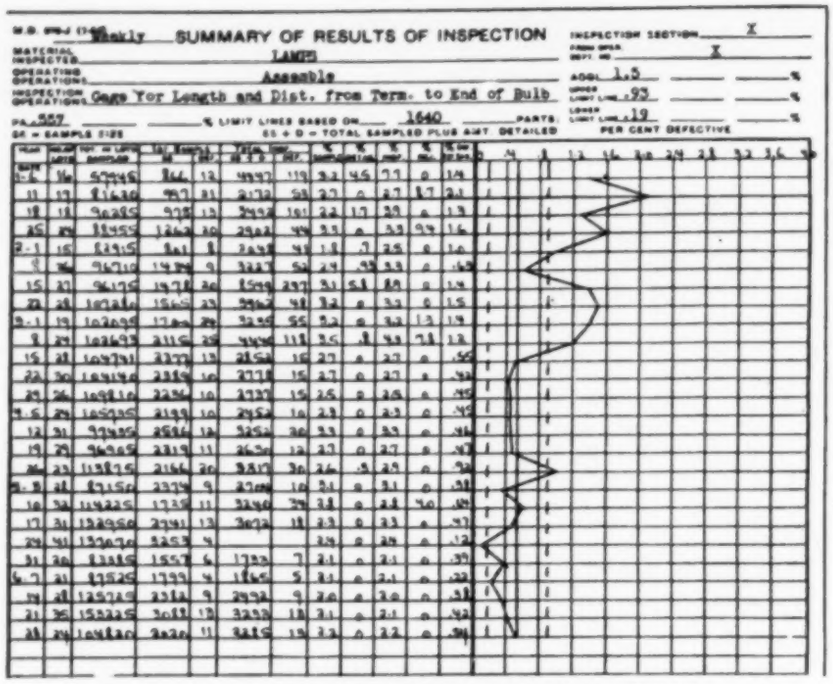
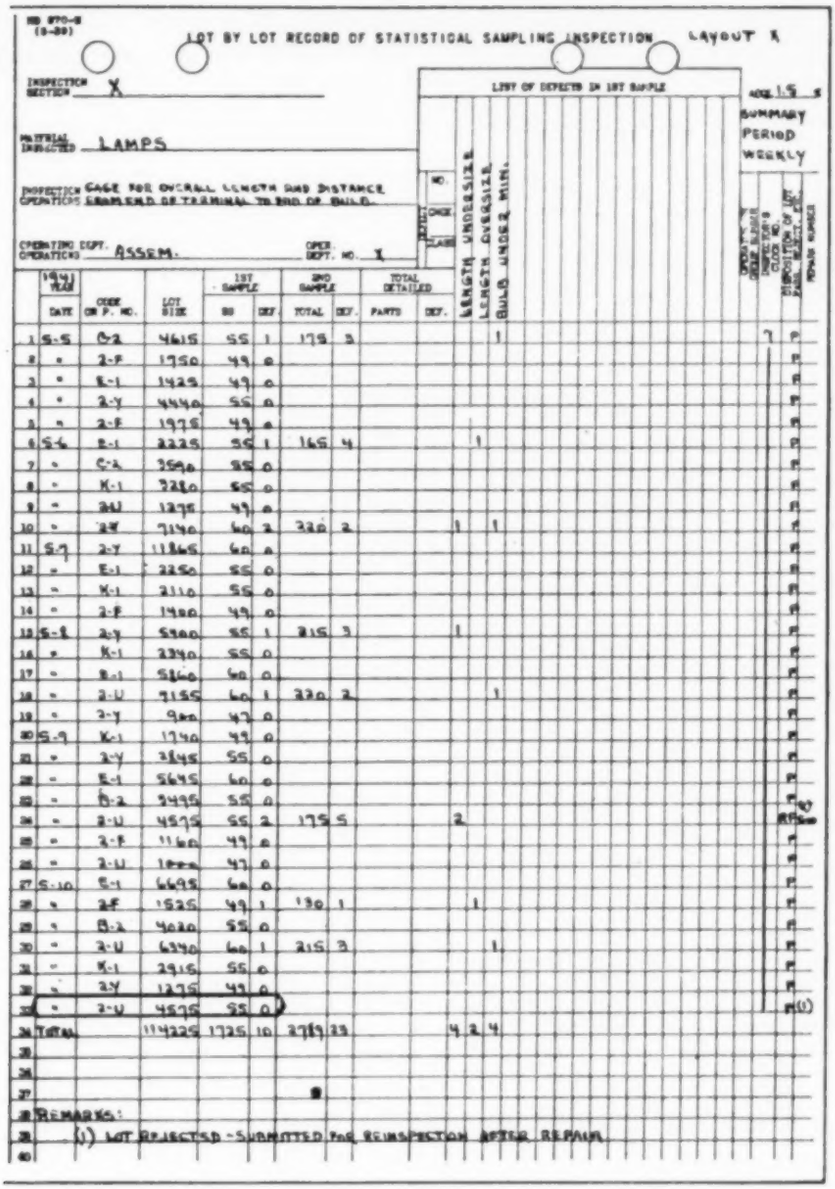


FIGURE 2 — FORM FOR TABULATING LOT RESULTS
Reproduced from "Sampling Inspection Tables"
Dodge and Romig, John Wiley & Sons

TABLE 1. CHOICE OF AOQL VALUE — EXAMPLES

Description	Inspection	AOQL
Metallic and Non-Metallic Rods, Tubes, Strips, and Sheets	Visual, Dimensional	3.0%
Milled Parts	Visual, Dimensional	0.75
Molded Plastic Parts	Visual, Dimensional	1.0
Die Cast Parts	Visual, Dimensional	1.0
Formed and Drawn Parts	Visual, Dimensional	2.0
Ferrous and Non-Ferrous Castings	Visual, Dimensional	3.0
Machine Screws	5 Dimensions	2.0
Hexagon Nuts	Visual Inspection after Zinc Plating	2.0
Twin Eyelets	6 Dimensions and 4 Visual Requirements	3.0
Ceramic Insulators	Visual, Dimensional	5.0
Misc. Inexpensive Electrical Apparatus	Breakdown	0.25
Misc. Completed Electrical Apparatus	Resistance	0.5
Relay Coils*	Inductance and Electrical Breakdown	1.0

*This is a process check for the specified requirements which is supplemented by another sampling inspection after assembly.



LOT BY LOT RECORD OF STATISTICAL SAMPLING INSPECTION — LAYOUT X

INSPECTION SECTION: X

MATERIAL INSPECTED: LAMPS

INSPECTION OPERATION(S): GAGE FOR OVERALL LENGTH AND DISTANCE FROM END OF TERMINAL TO END OF BULB

OPERATING DEPT. OPERATION(S): ASSEM. OPER. DEPT. NO.: X

LIST OF DEFECTS IN 1ST SAMPLE — AOQL: 1.5 %

SUMMARY PERIOD: WEEKLY

	1941 DATE	CODE OR P. NO.	LOT SIZE	1ST SAMPLE SIZE	1ST SAMPLE DEF.	2ND SAMPLE TOTAL	2ND SAMPLE DEF.	TOTAL DETAILED PARTS	TOTAL DETAILED DEF.	LENGTH UNDERSIZE	LENGTH OVERSIZE	BULB UNDER 2 MIN.
1	5-5	C-2	4615	55	1	175	3				1	
2	"	2-F	1750	49	0							
3	"	E-1	1425	49	0							
4	"	2-Y	4440	55	0							
5	"	2-F	1975	49	0							
6	5-6	E-1	2225	55	1	165	4				1	
7	"	C-2	2590	55	0							
8	"	K-1	3250	55	0							
9	"	2U	1275	49	0							
10	"	2F	7140	60	2	320	2			1	1	
11	5-7	2-Y	11865	60	0							
12	"	E-1	2250	55	0							
13	"	K-1	2110	55	0							
14	"	2-F	1980	49	0							
15	5-8	2-Y	5940	55	1	215	3			1		
16	"	K-1	2340	55	0							
17	"	B-1	5160	60	0							
18	"	2-U	7155	60	1	220	2				1	
19	"	2-Y	900	47	0							
20	5-9	K-1	1740	49	0							
21	"	2-Y	3645	55	0							
22	"	E-1	5695	60	0							
23	"	B-2	9495	55	0							
24	"	2-U	4575	55	2	175	5			2		
25	"	2-F	1160	49	0							
26	"	2-U	1000	47	0							
27	5-10	E-1	6695	60	0							
28	"	2F	1525	49	1	130	1			1		
29	"	B-2	4020	55	0							
30	"	2-U	6390	60	1	215	3				1	
31	"	K-1	2915	55	0							
32	"	2Y	1275	49	0							
33	"	2-U	4575	55	0							
34	TOTAL		114325	1725	10	2789	33			4	3	4

REMARKS:
(1) LOT REJECTED - SUBMITTED FOR REINSPECTION AFTER REPAIR

FIGURE 3 — FORM FOR SUMMARIZING RESULTS
Reproduced from "Sampling Inspection Tables"
Dodge and Romig, John Wiley & Sons

CHOICE OF AOQL VALUES

Appropriate AOQL values depend on local conditions, and may not be prescribed by any fixed rules. As a guide to the choice of AOQL, examples of values used* in one shop under certain prescribed conditions are given in Table I.

FORMATION OF LOTS

In the administration of a sampling plan particular attention should be given to the formation of lots. A lot should consist of product that is available in its entirety for acceptance or rejection at one time. So far as possible, it should consist of articles which have been produced under what are judged to be the same essential conditions. An attempt should be made to avoid grouping together batches of product that are likely to differ from one another in quality because of differences in raw materials used or differences in manufacturing methods or conditions.

Where production is more or less continuous, the time element may often be the deciding factor in fixing the size of a lot, and convenience in handling may make it desirable to take an hour's, a half day's, or a day's production as a quantity to be considered as a lot for inspection purposes. The lot should be made as large as possible consistent with these considerations because the larger the lot, the smaller will be the proportion required in a sample. So far as possible, lots should be physically laid out in such form that each individual article is readily accessible to the inspector for sampling purposes.

SELECTION OF SAMPLES

The method of selecting a sample is of first importance, and should be such that the sample will fairly represent the lot. Rarely are the articles in a lot thoroughly mixed. Accordingly, the sample should, in general, comprise articles drawn from all parts of the lot, not from one general location. In each location all of the articles should be given an equal chance of being selected; the selection of each article should be without bias, that is, uninfluenced by any known or observed features affecting quality.

Inspectors should be thoroughly trained in the principles of sampling and in the procedures that are best suited for different types of lots, preferably by using experimental techniques.

RECORDING AND ANALYZING RESULTS

The advantages of preparing suitable instructions and standard forms for recording and analyzing results to simplify the work of the inspector and the analyst cannot be overemphasized. Three forms that have been widely used are shown in Figures 1, 2, and 3.

In addition, the posting of charts, with past results plotted as a curve and with space for adding new results promptly, can do much to create interest and pride in quality performance. A graphical picture of the history of quality is provided at a glance, facts are provided in a form that is understood by workers and supervisors alike, and misunderstandings and arguments are reduced by keeping everyone informed.

*Furnished by Mr. G. D. Milne, Western Electric Co., and supplemented by values published in REF. 2, p. 18.

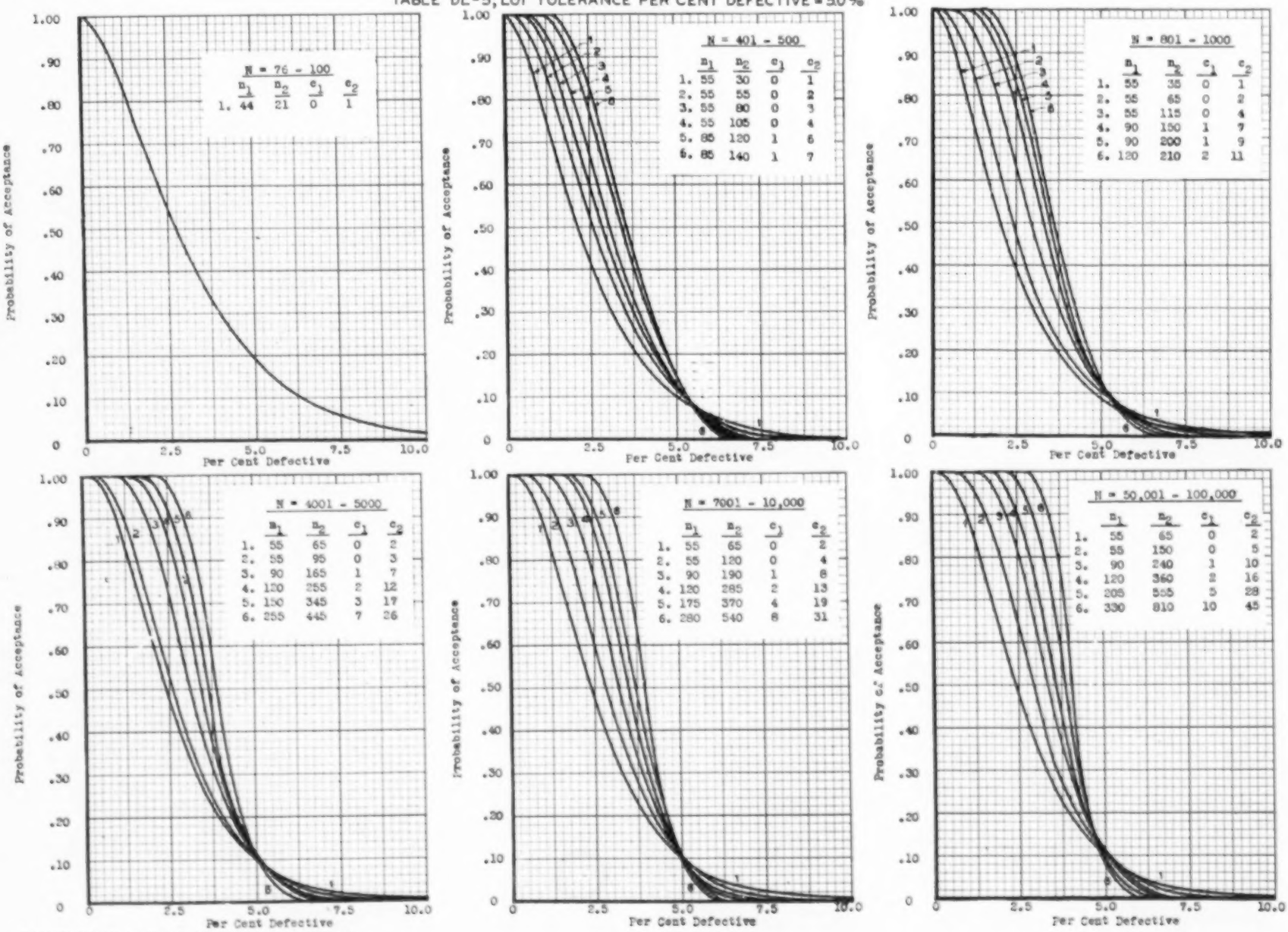
BELL TELEPHONE LABORATORIES
QUALITY ASSURANCE DEPARTMENT

10-15-48

FIGURE 4— OPERATING CHARACTERISTICS - DOUBLE SAMPLING PLANS

(PROBABILITY VALUES BASED ON POISSON EXPONENTIAL)

*TABLE DL-5, LOT TOLERANCE PER CENT DEFECTIVE = 5.0 %



*SAMPLING INSPECTION TABLES, DODGE & ROMIG

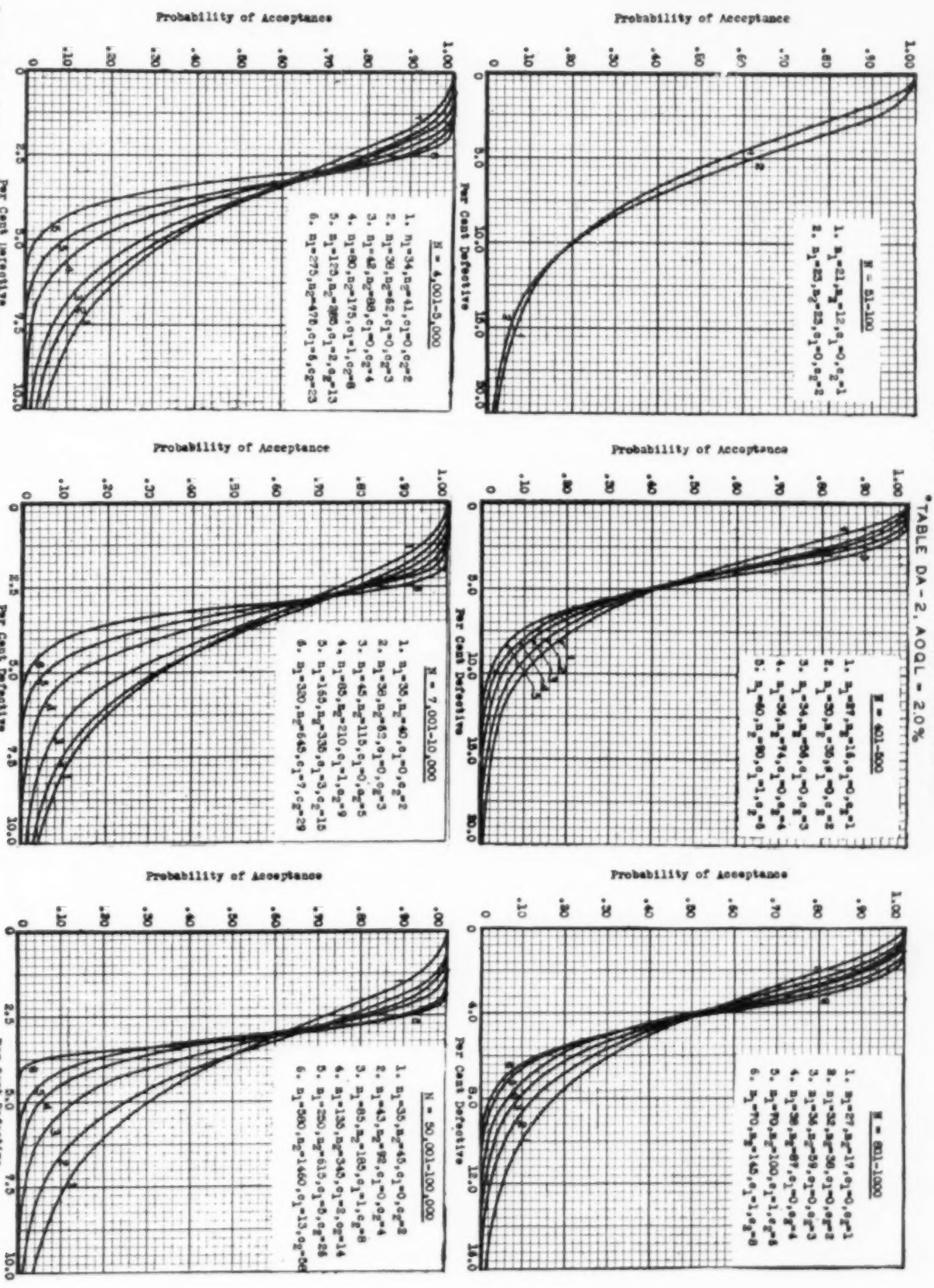


FIGURE 5— OPERATING CHARACTERISTICS - DOUBLE SAMPLING PLANS
(PROBABILITY VALUES BASED ON POISSON EXPONENTIAL)
*TABLE DA-2, AOQL = 2.0%

*SAMPLING INSPECTION TABLES, DODGE & ROMIG

10-14-48

CHARACTERISTICS OF PUBLISHED SAMPLING PLANS

Figures 4 and 5 give operating characteristics of sampling plans in two types of published* sampling tables, referred to as Lot Tolerance tables and AOQL tables, the first based on a fixed risk (10%) of accepting a lot of tolerance quality, and the second based on a fixed limit for average outgoing quality. A study of these two figures helps to indicate some of the basic differences between these types of plans. Each of the tables constitutes a system of plans, with provisions for shifting from one inspection plan to another, depending on the average quality coming to the inspector, so as to minimize the total inspection.

In explanation, it should be noted that the operating characteristic (OC) curve of a sampling plan as shown in Figures 4 and 5 indicates the probability of acceptance of lots for a **product** (or process) having a percent defective value shown on the bottom scale of the chart. These are obtained by assuming a binomial distribution of lot qualities, which distribution characterizes the minimum spread obtainable in the world of experience; a persistent distribution having a narrower spread of lot qualities could rarely be expected except through human manipulation. (It can be shown rigorously that random samples taken from a product comprising lots with such a binomial distribution may be treated mathematically as if they were actually samples from an infinite universe, that is **product** of p quality.)

Similar curves could be drawn showing the probability of acceptance for individual **lots** having the scale value of percent defective. The latter curves would indicate the value of the Consumer's Risk (at the lot tolerance percent defective point), and would coincide substantially with the curves of Figures 4 and 5 when samples are a small proportion of the lot, say less than 10%.

FACTORS RELATING TO SELECTION AND USE OF AN AOQL PLAN

The following items of interest are given in the light of wide experience in the use of AOQL plans in receiving, process, and final inspections.

(a) The AOQL can be computed for any inspection plan where the procedure involves 100% inspection of rejected lots and clearing them of defectives.

(b) Where procedure (a) is used with a plan having, say, a 1% AOQL, this means that the worst possible **average** percent defective in product after inspection is 1%. This worst quality is an extreme, reached only when incoming quality is consistently at some particular level worse than 1%. For all other incoming levels the average outgoing percent defective will be less than 1%; practically, as things work out in practice, the net result will usually be an average outgoing percent defective of not over 1/2 to 2/3 the AOQL value of 1%. Hence, if an outgoing quality of, say, .5% or .75% defective is considered satisfactory, choice of a 1% AOQL plan will, in general, be in order.

(c) The 100% inspection of rejected lots should preferably be performed by the producing organization in order to provide a maximum stimulus to control of quality by forcing correction of process. When producer and consumer are departments in the same company, this can be accomplished by an administrative procedure, which requires that rejected lots shall be 100% inspected by the producing department before they may be resubmitted. When the producer is another company, it can be accomplished by contractual agreement using a suitable certification system regarding reinspection of rejected lots. In specific cases, the 100% inspection may, of course, be performed by the consumer when this is advantageous because of manufacturing schedules or the supply situation.

(d) Doubt regarding use of AOQL tables sometimes rests on the misconception that AOQL tables apply only to a product for which production or supply is substantially continuous. Instead, the whole set of tables is commonly considered as a **system.** When the system is applied to a variety of different products, of either continuous or occasional production, then one may have confidence that, taken as a whole, the set of values of actual average outgoing quality will be better than the set of AOQL values of the plans used.

(e) It should be noted particularly that the process average need be estimated only approximately. Using the wrong column of a table merely means that, where rejected lots are inspected 100%, more total inspection will be done than necessary, but the protection to the consumer designated on the sampling table (Lot Tolerance value for 10% risk, or AOQL value), will be unchanged. If no process average information is available, it is usually advantageous to use one of the last two or three columns of the table.

(f) Even though rejected lots are not 100% inspected, the AOQL tables may quite properly be used in the light of the operating characteristics of the plans. (See Figure 5.) First, product having quality equal to or better than the process average value for the table column used, will have a very high probability of acceptance — usually over .98 or .99; seldom under .95. This is a consequence of solving the problem of minimum overall inspection. Second, lot quality values for which the probability of acceptance is .10 are shown on the tables. Third, product having a percent defective moderately

*REF. 2.

higher than, say one and a half times, the AOQL value of the plan used will be subject to substantial rejections, commonly sufficient to force corrective action by the producer. For example, for the 2% AOQL double sampling tables, and for product quality one and a half times the AOQL value, there will generally be 15% to 30% rejection for lot sizes under 1,000, and 25% to 40% for lot sizes over 1,000. (See Figure 5) Thus, while there will be no guarantee that the average outgoing quality will be better than the AOQL value if rejected lots are not inspected 100%, experience indicates that the plan, through its power of rejection, will tend to compel the producer, in his own interests, to maintain a process quality level which at worst, will be little, if any, poorer than the AOQL. The pressure will generally be greater, the larger the lot size.

REFERENCES

1. American War Standard Z1.3-1942, "Control Chart Method of Controlling Quality During Production," American War Standards, New York, 1942.
2. Dodge, H. F., and Romig, H. G., "Sampling Inspection Tables — Single and Double Sampling," John Wiley and Sons, Inc., New York, 1944.

The Foreman's View of Quality Control

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Editor's Note: This is the concluding portion of Mr. Weaver's paper, the first part of which appeared in the September, 1948 issue of IQC.

USE OF A SIGNIFICANCE CHART

An example of a somewhat different technique is one involving the accumulation of data on production runs to verify experimental data. In such cases the question always arises of how much data will be required. How long shall we run? How many shall we make? Various individuals or departments will select a figure based on "experience," which is usually little more than a guess. There exists, however, a very powerful control technique which fits this situation admirably. It is called a "Test for Significance," and it may be supplemented with a "Confidence Limit" test.

In the problem charted in Figure 16, we were interested in determining what effects a certain steel making technique had on yield when compared to the standard practice in use in a certain plant. The Metallurgical Department set up the experiment and decided that 30 heats of steel of each type would be required, but the quality control man was able to persuade them to secure the data in such a manner that it could be used statistically.

This chart is a cumulative difference chart; each result from the special practice is shown on the top half of the chart and each result from the standard practice on the bottom half. The first point of the middle line is the difference between the upper and lower values, the second point is the difference between the averages of the first two values in each case, the third point is the difference between the averages of the first three points, etc. This tells us, as the study progresses, the total accumulated difference, and as long as the central line is changing its direction we have insufficient data, but as soon as the line assumes a horizontal direction we can be "reasonably" certain that further study will induce no further change in the total results. How often have you seen "comparison" studies

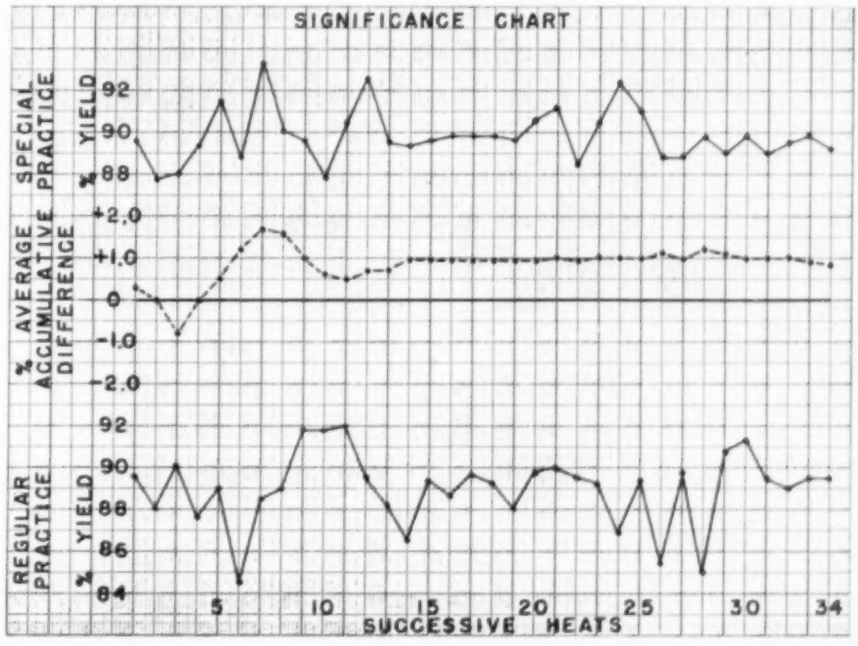

FIGURE 16—SIGNIFICANCE CHART

made in which the results of the "special" were averaged and balanced against the average of the "standard" practice, and conclusions drawn? Too many erroneous conclusions are arrived at by these antiquated methods. Averages, of themselves, are sometimes meaningless, but here is a technique that is really useful.

Note that while 34 pairs of heats were actually made, the same answer could have been obtained in about half that number, thus materially shortening the job, and with confidence. Just what is this confidence and how is it derived? We shall omit the mathematics, but a fairly simple formula is applied to the data, and the answer that comes out is called the "confidence limits."* In this particular case a significant difference of 0.9% was found, and analysis of the data showed that if the experiment were repeated under similar conditions, 99 times out of a 100 the balance would be in favor of the special practice, and that 95% of the time this difference would range from 0.27% to 1.49%. All we have to do is evaluate an improvement of 0.27% or more to determine if the considered changes in practice should be made. These confidence limits give considerable assurance to a foreman who is anxious to improve conditions; they give him something to which he can pin his faith and something with which to justify his actions to his superiors; something more than opinion or guesswork.

HOW CORRELATION STUDIES CAN HELP

Another technique, which is a little more complicated and which requires some experience in working with mathematical formulae, is that of correlation. There are both simple and multiple types of correlation analysis, and these can be extremely useful to an enterprising foreman. Consider the case of a department performing work on an already partially processed article, where the mistakes of the prior department affect the cost in the department under consideration, as well as the quality of the product leaving it. Frequently the foreman of such a department will be reasonably convinced that he is almost powerless to reduce the costs or improve the quality unless certain conditions existing prior to his department are improved, yet his efforts to sell these convictions to his supervisors will more often than not be received as excuses for his own short-comings.

Industrial Experimentation, K. A. Brownlee, Chemical Publishing Co., Inc., Brooklyn, N. Y., 1947; pp. 28-29.

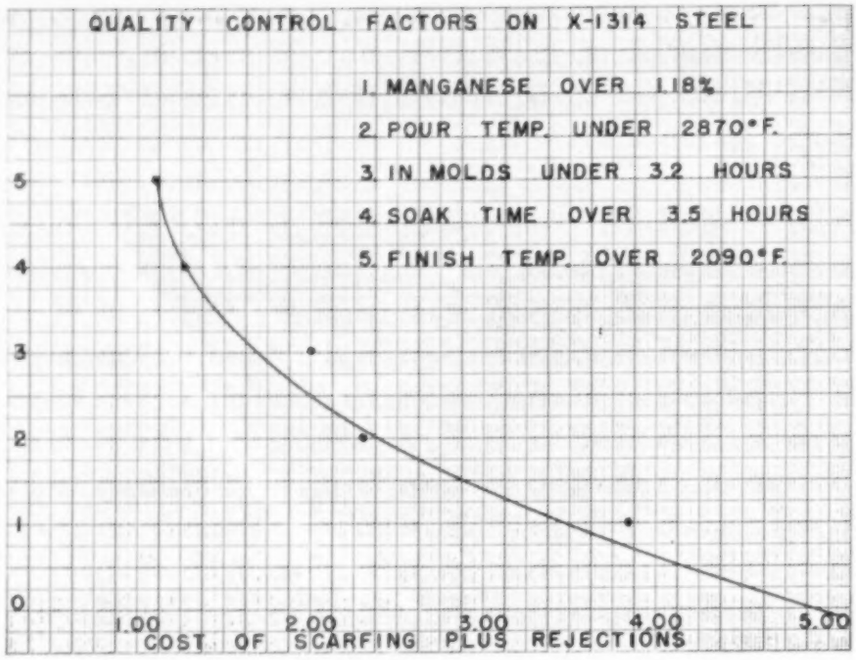

FIGURE 17—EFFECT OF CONTROL FACTORS ON SURFACE COSTS FOR X-1314 STEEL

We were particularly interested in studying the causes of poor surface quality on a specific type of steel at a certain point in the operation, and there were 14 factors, known, or believed, to have an important effect on it. A correlation analysis brought out that actually there were only five factors of any importance worth considering. These are shown on the chart in Figure 17, arranged in the order of their importance as determined by the correlation factors.

The data were then analyzed from a cost standpoint and arranged to show the importance of adhering to prescribed practices in the preceding departments insofar as its economic effect was related to the surface cleaning department. The chart shows that if all five factors are kept in control, the cleaning cost will be only $1.06 per ton and that this cost will increase as control is lost over one factor after another, in turn as listed, until if all five factors get out of control, it will amount to $4.92 per ton. In this manner the foreman of the cleaning department was able, not only to convince management that the greatest help to reducing costs in his department depended on other departments, but also to be specific about what should be done in those departments. This is the kind of evidence that is readily understood by management.

Many problems involving a number of factors can be resolved only by techniques such as this. Once again, guesswork or opinions are eliminated; facts are disclosed.

ANALYSIS OF VARIANCE EXAMPLE

Another still more complicated situation is one where there are, for instance, two forces affecting the end result and it is desired to know which one (and to what extent) would be the major offender if the interaction of one on the other were removed. This is resolved by a technique known as "Analysis of Variance." There are very few foremen, unfortunately, who can handle this technique; a typical application would be in research or development work.

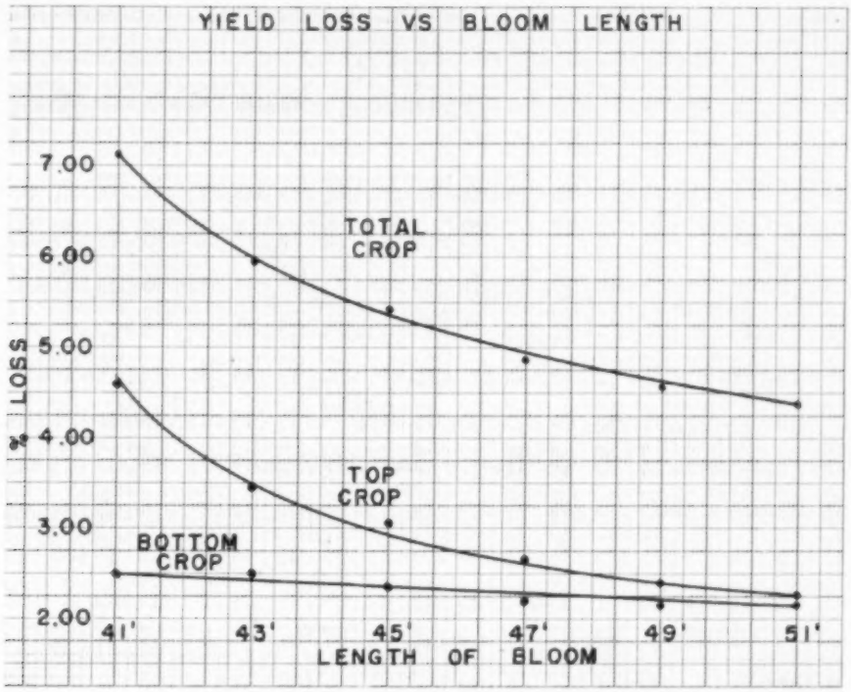

FIGURE 18—YIELD LOSS VS BLOCK LENGTH

We were trying to determine the cause for variation in yield on Bessemer steel in rolling. Our problem was to determine whether the observed variations were **between** lots, or "blows" as we call them, or **within** lots. If we knew this, we believed we could take corrective steps, so analysis of variance was put to work.

First of all, a correlation analysis disclosed that the most significant factor involved was the length of the bloom as rolled from the ingot. Figure 18 shows how the loss increased as the bloom length decreased. It further shows that the loss from the top of the ingot was mainly responsible for the total loss. What causes unusual losses from the top of an ingot? There are several causes, and naturally, we are fairly familiar with them, so it became necessary to know whether the causes involved in this particular case existed within blows or between blows. An analysis of variance test applied to our data gave the answer.

The mathematical computations are too involved to be covered here, but through a manipulation of squares of the numbers involved in the data and a few formulae we arrive at the "Variance Factors." The table in Figure 19 shows that the greatest variance is found "within blows," but to make certain we should test the data to see how much the total expected variation in loss would be reduced if we remove the effect of one variable at a time. The table shows that if we remove the effect of "within blows" the decrease is considerable, 8.20% to 3.52%, as compared to the decrease 8.20% to 7.44% when the effect of "between blows" is removed. We are, therefore, assured that we must concentrate on conditions existing within blows.

Naturally, the shorter bloom must come from a shorter ingot, all other things being equal, so we studied and tabulated all known causes for short ingots, of which we found five.

Figure 20 shows tabulation, by months, of the percent of ingots observed to be short, classified by cause; note that we accounted for practically all of them under five headings. Groups A and B are the ones showing variability, A increasing and decreasing with the total, but B increasing steadily. Our primary aim was to reduce loss, or to improve yield, so the last column shows the mill yield. June was a record month for yield, but an inverse relationship of yield to percent of short ingots is observable in the table.

One particularly illuminating thing about this study centers in cause C which happens to be a factor known for years by the operators to be injurious, and advanced by them as an alibi for poor practice. Notice that in the month of November this factor reached a new low, yet the percentage of short ingots was at an all time high. It is obvious that this problem is far from licked, but at least we have pinned down the causes and made the problem purely an operating one.

A FOREMAN WHO USED GOOD PSYCHOLOGY

Each month the participants in the incentive bonus plan previously described have a meeting in their respective departments for the purpose of discussing thoroughly the various factors that have influenced costs and production for the preceding month. At this time, also, the effects of these various factors on the bonus are discussed. One specific case, illustrating the important part played by the foreman in such matters, will be of interest.

A quality control chart of the X-bar and R type, based on a three month's history period, had been set up on a certain factor prominent in the incentive bonus plan, and had been carefully explained to the foremen involved. It brought out, as these charts almost always do, that of the four turns involved one was distinctly below the other three every month, two were close to the general over-all average, and one was well above the average. It was obvious that the turn making the poorest showing needed help.

After a 60 day period all turns seemed to maintain about the same general level and relative position. After repeated discussion of the chart with the foremen, one foreman suggested that the chart be shown and explained to the men actually doing the job. The results were almost instantaneous.

In another 60 days the turn previously the lowest of the four had attained a level approximately equal to that occupied previously by the highest turn. The former "leaders," seeing themselves gradually overtaken, pushed their average even higher. The net result in 90 days was an over-all process level improvement of 3%. This might be called a "psychological result," but it was due to the action taken by an enterprising foreman.

CONCLUSION

In this paper we have seen considerable evidence that quality control can be an extremely valuable tool to the foreman. But whether it be foreman, superintendent, manager, or president he will be faced with making decisions. There are four ways to arrive at decisions. The first is the "rule of thumb," and that is a pretty good way to go broke these days. The second is by "intuition," and a classic example of this is the Director of the U.S. Patent Office in 1886, who recommended to Congress that the Patent Office be discontinued because everything worthwhile had been invented! Modern thinking on the part of some people hasn't changed much. The third is by "brains," illustrated by the banker who was approached by a good customer for a loan to expand a women's hat business in 1927 when women's skirts were growing shorter all the time. The banker decided that for the near future the eyes of the admiring public were going to be more toward ladies' shoes than toward their hats, and so refused the loan. But how many of us have that kind of "brains"? The fourth is by "facts," and quality control will give us the facts. Let's see that the foreman is provided with facts!

ANALYSIS OF VARIANCE — SUMMARY TABLE

BESSEMER BLOOMS — — AUGUST, 1947

SOURCE	SUM OF SQUARES	MEAN SQUARE	VARIANCE	EXPECTED VARIANCE	ACTUAL VARIANCE
BETWEEN BLOWS	114.42	6.02	.80	8.20%	3.52%
WITHIN BLOWS	144.85	3.62	3.62	8.20%	7.44%

FIGURE 19—ANALYSIS OF VARIANCE SUMMARY TABLE

PERCENT OF SHORT INGOTS BY CAUSE

MONTH	TOTAL	A	B	C	D	E	MISC.	YIELD
JUNE	8.0	1.8	0.5	3.3	1.6	0.4	0.4	89.6
AUG	13.8	6.8	1.6	3.1	1.5	0.4	0.4	88.5
SEPT	11.5	3.4	2.1	3.7	1.5	0.2	0.2	88.9
OCT	10.2	2.4	2.4	3.1	1.2	0.2	0.2	89.5
NOV	13.9	4.1	5.6	1.7	1.7	0.0	0.0	88.5

FIGURE 20 — PERCENT OF SHORT INGOTS BY CAUSE

Quality Control---Sales*

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INTRODUCTION

When I was asked to discuss the subject of this paper, I suddenly realized how much time had slipped by since I was actively in Quality Control work. Despite my intention to keep up with the progress of the American Society for Quality Control through reading Industrial Quality Control, I have not done so, and I felt "out of touch." So, I sat down with the last 10 or 12 issues and went through them. I then realized how much Quality Control has grown. All of you who have had a part in the growth should be pleased and proud.

The theme, "Quality Control in the Coming Buyer's Market," is one I can heartily subscribe to. However, I believe that the Buyer's Market is here in many fields, so I shall frequently speak of the

*Presented at the Second Annual Convention and Fourth Annual Rochester Clinic, ASQC, Rochester, N. Y., February 17, 1948.

Buyer's Market in the present tense rather than in the future.

THE PART OF SALES IN QUALITY CONTROL

The three major parts of the productive core of any industrial enterprise are:

1. Engineering and Development;
2. Manufacturing;
3. Sales.

Considering Quality Control, for the moment, as an industrial product, it seems reasonable to suppose that Dr. Shewhart's invention of Statistical Quality Control was developed as a practical tool through the early Western Electric and Pickatinny Arsenal installations, to mention two.

The ESMWT courses, the local societies that grew out of the courses, the various University and College training courses, and now the American Society for Quality Control have all provided the trained manpower which can be considered as the manufacturing capacity of the product "Quality Control".

The analogy thus far has established the product, its invention and development, and a manufacturing capacity.

But, how about the Sales Program for the product?

From the beginning, attempts were made to "sell" management on the importance of Quality Control. In the high production days of World War II, there was at first reluctance to allow introduction of anything that might interfere with production, but nevertheless there was a rapid growth in the introduction and use of Quality Control during this period. Quality Control departments were started and flourished, and many of them produced good results.

Much of the credit for this growth and acceptance is usually given to the willingness of some managements to try anything that might increase the amount of good product required to meet the volume demanded by the armed forces. Cost savings were an important consideration, and in many cases were the entering wedge in convincing management that Quality Control should be given a trial. But, in similar conditions of great difficulty in getting out acceptable production, some managements were "sold" on putting in Quality Control, while others were not. Some, unfortunately, were oversold. Of course managements differed widely in their resistance to acceptance of Quality Control, but it is probable that the excellence of the "sales" presentation to management was a factor not always given sufficient weight.

During the war, Sales Departments were reduced drastically and sales personnel were frequently brought back into the factory. Expediting, Purchasing, and Inspection were popular activities for former sales personnel. Some displaced sales personnel wound up in Quality Control. It is likely that where more good sales thinking went into a Quality Control presentation, the chances of acceptance were greater. People who do sales work have no corner on ability to make successful selling presentations. I know many factory managers, inspectors and engineers, who have top sales ability. Nevertheless, people doing sales work successfully as a full time job will have more sales "savvy" and know-how.

These considerations therefore suggest that although the Development and Manufacturing phases of the product, "Quality Control", have advanced steadily, the Sales Program has not kept up with these advances. Actually, a good Sales program should be leading and creating the demand for increased development and increased capacity. Those of you who may have watched a Sales Department take hold of a newly developed product and evolve and establish a promotional selling campaign for the product know what is meant.

The point is therefore made that in many cases the product "Quality Control", is not getting the Sales Promotion it needs. The Sales Department can help and should be enlisted in promoting Quality Control. Sales has a vital interest and can contribute a great deal. In addition to the promotional skills that the Sales Department can contribute, there is now the very important influence the Sales Department can exert on management.

Most companies aim at a balanced effect of the major divisions on management decisions. But, circumstances frequently alter this balance. For instance, during the war and in the seller's market following it, production was the all important, primary objective. In the face of rising costs, increased volume was the answer. There is no doubt that the Manufacturing Divisions were in the saddle during these times.

On the other hand, in a buyer's market, the sales order once more becomes the primary, all-important objective, and the man in charge of getting the orders finds himself carrying more weight in management decisions than perhaps was the case during war periods and seller's markets. This suggests that increased attention be given to the problem of training Quality Control operatives in the techniques of selling to management. In this training, it would be well to include some selling suggestions which, if not planned by salesmen, at least are based on successful sales policy.

This is one of the most difficult types of selling, as most of you know. It requires special skill and unusual approaches. Industrial consultants, in selling their services to top management, have carefully worked out sales approaches that have a remarkable history of achievement. A study of the techniques used by them will increase the rate of sale of Quality Control programs to your own top managements.

Too often, "Quality Control", the product, is sold, or the attempt is made to sell it, on price alone. Because Manufacturing Divisions have to be cost conscious, the tendency is to sell Quality Control on cost saving alone. It is possible to develop the intangible of consumer satisfaction, fewer complaints, servicing, distribution factors, and many other points. Perhaps most important may be the effect of Quality Control on the Sales Program of the company. This may take some time to develop, but the effort will be worthwhile.

SALES INTEREST IN CONTROL OF PRODUCT QUALITY

Quality of Product is one of the main reasons for the existence of Salesmen and Sales Departments when a market exists for the product. If all brands of a given product were made to exactly the same specifications, a manufacturer would need only to print a price list and, if his price was low, he would get the order.

However, if he makes a better product that costs more, but will give longer and more satisfactory service, then he needs a salesman to explain to the customer the advantages of the more expensive product. If his salesman successfully convinces the customer, he gets the order at the higher price. Basically, the Sales-Customer relationship revolves around convincing the customer that your product has the Quality-Price relationship he needs. It follows that the maintenance and control of this quality between satisfactory limits is basic to the continuance of the relationship.

During the last year of World War II, Sales Managers turned their attention to the coming Sales problems. Forward looking groups, like the Committee for Economic Development, The National Association of Sales Executives, and others, spear-headed national programs of education and training in an effort to provide the sales capacity to bring in the orders to support our greatly expanded manufacturing facilities.

It was generally recognized that salesmen of the future would have to be much better informed technically. The selling of the Quality of the product was seen to be the most important single fundamental, which implied an intimate knowledge of the product and its applications to the consumer's needs. The selling of the Quality of the product can be more tangible selling if the product is made under truly controlled processes. Such selling need not be limited to generalizations of branch names, company reputation, etc. Indeed, the wary purchaser today is only too cognizant of the falling off in quality during the war years and of the relatively slow return of lost quality in the high production post-war years.

In too many instances, the loss in quality of product during the war years represented a greater loss in purchasing power of the consumer's dollar than the inflation on the price tag of the goods. Established manufacturers of finished products know this and are honestly attempting to re-establish the lost quality standards and to improve them.

The higher, more consistent, quality which can be achieved through Quality Control will go a long way toward counteracting price inflation, because the increased wearing value reduces the replacement and repair costs. The cost reductions through increased efficiency and Quality Control procedures will help justify price reductions while maintaining adequate profit levels.

Since the removal of price controls, mounting manufacturing costs of products have been taken care of by increasing consumer prices. But, there is a limit to what the traffic will bear, and in some products this limit has already been reached. In a buyer's market, manufacturing costs do not determine consumer price, and we are now in that undesirable situation where costs are still rising and buyer resistance is either forcing prices down or is about to do so. Even in those fields where the price turning point has not yet been reached, the increased cost of selling the product has diluted the effect of price increase on net profit. In such an economic dilemma, Quality Control becomes of even greater importance than it was during the war period.

During the war, Quality Control was primarily a means of getting more product accepted; any attendant cost saving was of secondary importance. Quality Control had no effect on Sales because there were no Sales problems. Everyone had more orders than he could handle.

Now, Quality Control contributes on a much broader basis by:

1. Reducing manufacturing cost of product;
2. Increasing life, lowering maintenance, thereby counteracting inflation in price;
3. Providing tangible selling aids;
4. Improving consumer relations through maintenance of consistent quality, or simply, fewer complaints.

With the availability to the salesman of usable Quality Control information, and the understanding of this Quality Control information by purchasers, comes a new tool in selling. A new and improved sales-consumer relationship is developed on a sounder basis. Quality Control has long been termed a tool of Management. It can also be a very effective Sales tool.

USE OF QUALITY CONTROL TECHNIQUES BY SALES

A. FORECASTING—MARKET POTENTIALS

In a war period, in fact, in any seller's market, sales forecasting becomes somewhat simpler. Due to a number of circumstances, plant capacity, availability of materials, available capital, etc., it is likely that the sales forecast that is finally accepted will be determined by ability to produce. There is no need to worry about the precision of the forecast when it is not possible for Sales to get all it can sell. Just so long as it is high enough, as it always will be in a Seller's market, the forecast will be accurate enough for practical use.

But Sales Forecasting in a Buyer's Market is quite a different thing. As a Buyer's Market approaches, and in a Buyer's Market, there is need for greatly increased precision in Sales Forecasting. Still greater precision is desirable in the current situation, since tooling costs are higher than ever in an effort to counterbalance higher labor rates. With increased tooling, less direct labor goes into the product. Job simplification and other factors contribute to reduce flexibility in manufacture. Manufacturing cycles have increased in many instances, so that forecasts have to be made further ahead. Inaccuracies in forecasting have become more costly to correct.

On top of all this, it is not always possible by present techniques to explain the swollen volume of orders. Long after volume should have dropped off, orders continue to come in and Sales Departments are at a loss to explain why. There

must be contributing factors that are not fully understood. Counteracting and unknown variables are present. Abrupt changes in these variables, undetected by present techniques, can cause unbalanced inventories, costly cutbacks, and over-large shelf stocks.

In any case, few Sales Managers have the sort of market reaction data with respect to time that they would like. In Quality Control language, control charts are not available in this field to show that assignable causes are present in the sales distribution process which should be found and corrective action taken. A shift in customer emphasis in a line of product from Style A, the present leader, to Style B cannot be anticipated quickly enough.

Market analysts and sales statisticians are contributing, but often the basis of their conclusions is not understood by product sales managers and, conversely, the statisticians do not always understand the Sales factors. Further, not many analysts are skilled in the use of Quality Control techniques, or at least have not applied simple control charts to the Sales and Distribution process.

The intelligent application of Control principles can improve Sales Management for the general good of the whole company. For instance, random sampling of weekly orders by geographical location when made into control charts can detect sales trends long before customary methods of sales analysis.

Just as in the factory all sorts of inspection records are kept to little avail until Quality Control is applied and useful and pertinent data are taken and used, so in most companies, much money is spent on compiling various sorts of Sales records and, while they are used, Sales Managers need answers that these records do not supply, in the absence of the Quality Control type of analysis.

Fortunately, the Sales process can be varied to allow for market changes and forecasting errors can often be remedied by increased sales activity, if the error is positive, that is, if the forecast was too high. If it was too low, it is never known how much business was lost.

The application of Control techniques to Sales is not easy and requires considerable ingenuity and study. But, the experience gained in production Quality Control in any company will help a great deal. Engineering and manufacturing Quality Control personnel will find it worthwhile to encourage their Sales Departments along these lines.

As an example, sudden cutbacks in production, due to sharply falling volume in some items, are embarrassing to the Sales Department, but the impact of the headaches involved is likely to be more keenly felt by the Manufacturing Division in rearranging production schedules and by the Engineering and Development Departments in the "crash" programs likely to result from the demand for a new product or acceleration of one already in development.

B. SALES QUOTAS, TERRITORY POTENTIAL, SALESMEN'S PERFORMANCE

In Forecasting, we are concerned with overall potential and attempt to translate it into factory orders.

Establishing Territory Potential and judging salesmen's performance are other problems where Control techniques should be helpful.

Additional variables, such as geographic preferences, climate, and other factors, are recognized and taken into account, but a more precise evaluation is needed.

C. CONSUMER ATTITUDES AND COMPLAINTS

Dr. Shewhart and others have been actively extending the application of Quality Control principles to the study of consumer attitudes, gripes, and complaints. One session of the Princeton Conference was devoted to this last December and undoubtedly more and more attention will be given to this phase of sales-consumer relations.

During the war, most consumers understood and made allowances for the lowered levels of quality. During the past several years, consumers have shown less and less patience with deviations in quality from expected levels. The number of desperation "letters to the president" complaints hit an all time high during this period. While delivery was the subject of many, quality and poor customer relations were mentioned in almost all such letters. The evaluation of these is difficult, but the cost of taking care of them and rebuilding lost good will is staggering.

In Sales, we speak of immediate advantage at the point of sale, and this is an important factor. But, the success of any company is actually the result of a composite impression its customers have of the company. Loss of important accounts, inability to break in on a big user of the product, may depend on small incidents in these relations. Consistent control of quality of product will do a great deal to build up a sound, satisfactory, composite impression.

Fuller recognition must be given to the normal difference in attitude between a factory man at the plant and a salesman at the point of sale in judging the importance of small defects in the product. Evaluation of the cost of rejection at the factory final inspection against cost of customer complaint is needed. The cost of regaining customer good-will is difficult to determine, but its magnitude can be estimated closely enough to warrant spending sufficient money at the factory to reduce the possibility of occurrence to a minimum.

CONCLUSION

In summation, Sales needs Quality Control and Quality Control can profit by Sales help.

At the Society and Association level of activity, consideration should be given to joint discussion. If it has not already been started, co-operative action by the American Society and some National Sales Group, as for instance, the National Association of Sales Executives could do a great deal to foster development and general adoption of these valuable techniques by Sales Management. But, the real start will be made when competent Quality Control men work out with their Sales Department a real application that will catch the attention of the Sales Management.

Many of you in the Society could do this if the circumstances were right and you had the time. I hope some few of you **will** actually do it and pioneer an important new field. The need is great and urgent. It presents a challenge Quality Control men must accept.

Book Review

INDUSTRIAL EXPERIMENTATION

A guide to the planning and interpretation of experiments in industrial plants. Kenneth A. Brownlee. Chemical Publishing Co., Inc., Brooklyn, N. Y., 1947; 151 pp; $3.75. Review by J. A. Fizzell, Illinois Testing Labs, Chicago, Illinois.

The infusion of statistical methods into industry through the medium of the quality control departments has in most instances been a fortunate occurrence, and the diffusion of statistical methods into sales, planning, and engineering departments has also been quite helpful. With the dissemination of more practical knowledge, however, these methods will become indispensable.

It has been known for several years by a limited number of people that the hunting for trouble in industrial processes and the testing of new products during development could be done more efficiently if the necessary tests and experiments were planned and conducted according to appropriate statistical methods. To explain this general idea, Prof. R. A. Fisher wrote a small book called "The Design of Experiments," and other authors have devoted sections of their books to the subject of experimentation. Most of their examples, however, were agricultural, biological, or medical and hence were not very attractive nor enlightening to industrial men. A complete book treating this subject from the point of view of industry has been needed. Drawing upon the theory developed by Fisher and upon experience gained in Royal Ordnance Factories (Explosives) of the British Ministry of Supply, Mr. K. A. Brownlee has prepared such a book aptly named, "Industrial Experimentation."

Kenneth Alexander Brownlee was born in England and is a British citizen residing in London. His close contact with both pilot plant and plant scale experiments in chemical manufacturing processes has enabled him to write in a concise, matter-of-fact style that wastes no words. Numerical examples are his principal means of exposition and although they are all derived from the chemical industry, Mr. Brownlee deserves much credit for showing the calculations and stating the applicable principles in such form that a person having the assumed technical background should be able to translate them into his own field.

This assumed technical background includes (1) an interest in and the responsibility for conducting investigations by means of experiments on an industrial scale, (2) a fair knowledge of modern statistical methods, (3) a realization of what is meant by tests of significance but not a full theoretical knowledge, (4) a previous introduction to design of experiments, and (5) the ability to think in terms of statistical concepts.

The book begins conventionally with a table of contents revealing 15 chapter titles and an average of 7.33 section headings per chapter, indicating a thorough and systematic breakdown of the subject. One appreciates this when he starts to use the book because it may be thought of as a handbook in which to find promptly an arithmetic example for any one of many different kinds of experimental designs.

Chapter I is a prelude to the book and in it one can see that this is not intended as a **textbook** on either statistical methods or the design of experiments. Emphasis is placed on routines for handling data; it presents, in the author's own words, "a convenient account of the straight-forward tests of significance written from the point of view of the individual who has to apply them without necessarily a full knowledge of their theoretical background." This chapter also presents definitions of many of the terms commonly used in the discussion of the statistical aspects of experiments.

Chapters II, III, and IV present adequate reviews of fundamental statistical concepts, significance of means, and the comparison of variances. In reading through the lucid examples described in these chapters, one learns of the existence of certain important tables that are included in the appendix. There is the "Table of t" which is a tabulation of "Student's" distribution and there are tables of "Variance Ratio" which are the same as Snedecor's tables of F.

Chapter V introduces the Chi-square test and applies it to contingency tables having various numbers of squares into which data may be entered. No other applications are mentioned here although the use of Chi-square is briefly described in the previous chapter in the application of Bartlett's Test. Of course a table of Chi-square for ten levels of probability is included at the end of the book.

The Poisson Distribution and the Quality Control Chart are touched upon in Chapters VI and VIII but to such an incomplete extent that those subjects are better studied elsewhere.

An introduction to the analysis of variance is presented in Chapter VII in order that certain ideas brought out in it could be used in Chapter IX which is entitled, "The Relation Between Two Variables." As one might imagine, this chapter develops the ideas of linear regression and discusses their application to some experiments. Chapter X logically deals with multiple correlation. Realizing that his subject is getting more complex, Brownlee has written this chapter in a very lucid style and has presented detailed arithmetic calculations for an experiment involving two independent variables. Then he has repeated all of the tedious details for three independent variables. The thoroughness in this chapter is strongly reminiscent of Mordecai Ezekiel and his writings on multiple correlation.

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One gets the feeling in thinking back over this book that the author is just building up to the situation where he can present in all its majestic glory the whole scheme of analysis of variance. He touches upon it with ever-increasing pressure in Chapters II, IV, and VII, but in Chapter XI he really attains the climax and the subsequent chapters constitute the denouement.

Brownlee applies the principles of analyzing variance to a series of practical experiments falling into the following types: complete and incomplete factorial designs, the Latin square, Graeco-Latin and higher order squares, balanced incomplete blocks, and designs wherein confounding is required because of restricted block size. These applications fill the latter chapters of the book.

Although it may seem unduly sophisticated to industrial men, some mathematical statisticians question Brownlee's practice of lumping variances in setting up his tests of significance on factorial experiments in order to get tests which are not otherwise possible. As an example, the three-factor analysis described in Chapter IX is actually incapable of yielding a rigorous test for the significance of the main effects if interactions are present. The experiment does, however, permit rigorous testing of the interactions at known probability levels. Brownlee tests the interactions and then lumps the insignificant variances with the error variance to get a new value of residual variance for use in testing the significance of the main effects.

It is this latter practice that is frowned upon by statisticians who contend that all subsequent tests are performed at a completely unknown level of probability. Practically speaking, it means that our author, keeping an eye on the costs of experimenting, is endeavoring to extract a little more information from the data than is available within the assumed limits of confidence.

The investigator who seriously studies this book and takes it out in the plant will find it to be a valuable but incomplete aid in solving his problems. While the information in "Industrial Experimentation" is a **sine qua non,** the investigator's real difficulties will lie in assimilating the evidence of trouble in the plant, conceiving the experiment which should yield data to aid in clearing up the trouble, and then persuading the personnel of the plant to conduct the experiment reliably. How to surmount these difficulties is not explained in the book.

Guest Editorial

Public Opinion Polling and Industrial Sampling

MARTIN A. BRUMBAUGH — BRISTOL LABORATORIES

Many questions have been asked since November 3rd about the points of similarity and difference as between public opinion polling and industrial sampling. The basic principles involved are the same in one way, — both rely upon small representative samples to provide an estimate of the numerical value of characteristics. However, beyond this basic similarity there are many differences, — features of industrial sampling which simply cannot be duplicated in public opinion polling.

The public opinion poller attempts to name the fraction of the electors which will vote each way after, inspecting a sample from the electorate.

The industrial sampler does not attempt to name the fraction defective of a lot after inspecting a sample from that lot. When he accepts the lot, he is saying merely that there is no significant evidence from the sample that the quality of the lot differs significantly in process average or spread from the intent of the specification which the sampling plan has been set up to verify. When samples from a number of lots of the same material from the same producer have been inspected and the fraction defective of these samples shows control, then the producer's process average can be estimated within very close limits. Each subsequent individual lot from that producer is accepted if its sample shows no significant evidence that it differs from this process average.

It is not immediately evident just how a public opinion poll could be arranged to secure enough independent observations of its process (universe of voters) to use control chart technique, but the subject might warrant some investigation.

Assuming that some modification of control charting could be used however, the difference in operation would not end there. Imagine the squawks if an important number of bolts in an accepted lot could change to wood screws (voters who change their minds during a campaign), or if bolts could divest themselves of threads (eligible voters who do not vote), or if bolts could take on square or hexagonal heads at will as they were removed from storage (voters who are undecided). The fantastic character of this example may aid in showing the differences between industrial sampling and public opinion polling. The industrial sampler knows quickly when his material is not homogeneous and a rejection follows. The material is inanimate and fortunately, not subject to the Alice-in-Wonderland whims suggested above. A representative sample can be obtained with reasonable care, — an extremely difficult if not almost impossible task in public opinion polling.

To summarize,—industrial sampling and public opinion polling require two quite diverse operating techniques. These differ so much, in fact, that persons trained in either would have to be retrained to work in the other. Only the basic principles of probability cut across the two.

AMERICAN SOCIETY NEWS

BOARD OF DIRECTORS 1948-49

The terms of Directors representing the following Sections expired on June 30, 1948: Buffalo, Chicago, Dayton, Georgia, Illinois, Iowa, Milwaukee, North Eastern Indiana, Pittsburgh, St. Louis, Southern Tier, Tennessee, Toronto, and Washington. These Sections have now chosen new Directors to represent them on the American Society Board for the term ending June 30, 1950.

The Directors representing the Delaware, Mid-Hudson, and Ohio Sections of the Society have resigned and new Directors to fill the unexpired terms ending June 30, 1949 have been chosen by these sections.

The Rock River Valley Section, newest section of the Society, has appointed its Director to serve for the term ending June 30, 1950.

With the selection of these new Directors, the Board of Directors for 1948-49 is now complete and is constituted as follows:

Chairman:
Ralph E. Wareham, President
Wade R. Weaver, Vice President

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Simon Collier, Executive Secretary

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Martin A. Brumbaugh, Syracuse
Parker D. Deans, Tennessee
Byron A. Griffith, Toronto
A. L. Robertson, Washington
Joseph J. Ferri, Western Massachusetts

EXECUTIVE COMMITTEE 1948-49

New Regional Directors having been duly chosen to succeed all of those whose terms have expired, or who have resigned, the Executive Committee of the Society for 1948-49 is now complete and is constituted as follows:

Chairman:
Ralph E. Wareham, President
Wade R. Weaver, Vice President

Secretary:
Simon Collier, Executive Secretary

George D. Edwards, Past President
Alfred L. Davis, Treasurer
Mason E. Wescott, Chairman, Editorial Board
Elwood E. Folsom, Regional Director—New England
Irwin S. Hoffer, Regional Director—Middle Atlantic
Martin A. Brumbaugh, Regional Director—Northern
Ralph A. Hefner, Regional Director—Central
Arthur Bender, Jr., Regional Director—Mid-West
Wyatt H. Lewis, Regional Director—Western

The new Executive Committee met on Friday and Saturday, November 5 and 6 at the Hotel Sherman, Chicago.

SECTION OFFICERS MEET IN CHICAGO

During the Third Midwest Quality Control Conference, a meeting of Section Officers attending the Conference was held to discuss matters of importance in co-ordinating the affairs of the Sections and the American Society.

An outline of primary subjects to be covered in a manual of instructions covering section-national office relationships was reviewed at the meeting. Plans were made for developing this outline into a detailed manual, along the lines of suggestions made by those attending the Chicago meeting.

It was emphasized at the meeting that the efficient handling of membership records, changes of address, transfers of membership grades, transfers between sections and similar matters required close teamwork within the entire ASQC organization.

BRUMBAUGH AWARD APPROVED BY BOARD OF DIRECTORS

The American Society Board of Directors has approved the action of the Executive Committee in establishing the Brumbaugh Award of the Society. The Award will be made each year to the author of that paper published in INDUSTRIAL QUALITY CONTROL and judged to have made the greatest contribution to the development of industrial application of quality control. This award honors Martin A. Brumbaugh who founded INDUSTRIAL QUALITY CONTROL in 1944, published and edited the magazine during the first several years of its existence, and served as first Chairman of the Society's Editorial Board.

The establishment of the Brumbaugh Award has been made possible by the substantial Sustaining Contribution of the Rochester Section, following its successful managing of the Society's Second Annual Convention last February.

BRUMBAUGH AWARD COMMITTEE APPOINTED

With the approval of the Board of Directors, the President of the American Society has appointed the following Committee to constitute the Brumbaugh Award Committee:

Halsey H. Kent—Rochester Section—Chairman.
Joseph J. Ferri—Western Massachusetts Section.
Charles R. Scott—Philadelphia Section.
Parker D. Deans—Tennessee Section.
Charles S. Barrett—Chicago Section.
Wyatt H. Lewis—California Section.
H. Harold Sheaffer—At-Large.
Mason E. Wescott—Ex Officio.

The first responsibilities of this Committee will relate to formulating recommendations on the following points regarding the Brumbaugh Award:

1. The proportion of the Rochester Section Sustaining Contribution to be set aside for the purpose of the Award.
2. Whether merely the income, or a portion of the principal of this proportion in addition, should be used annually for the purposes of the Award.
3. The cash amount of the Award to be made annually.
4. The conditions under which the annual selection shall be made of the paper to become the basis for the Award.

The plans will become effective upon Executive Committee approval covering the above points.

THIRD ANNUAL CONVENTION ASQC

Plans are well advanced for the Third Annual Convention of the Society to be held in Boston on Thursday and Friday, May 5 and 6, 1949. The four New England Sections of ASQC will be host to the Convention which will be held in conjunction with the Third Annual New England Quality Control Conference.

Advance information concerning the Convention program and arrangements for scheduled events indicates that the 1949 Convention will be an event of outstanding importance in quality control affairs. The New England Sections are making every effort to provide a program of wide general interest and maximum value to members of the Society.

Mr. Warren R. Purcell, General Chairman of the Convention, has announced that there will be seven specialized sessions on the Convention program; one on Thursday morning; two on Thursday afternoon; two on Friday morning; and two on Friday afternoon. During each of these specialized sessions, there will be meetings devoted to particular themes that run throughout the Convention. One of these themes will likely be devoted to quality control as applied in different industries, another to round table discussions of the operating phases of quality control problems, another to management aspects of quality control work, and another to general introduction in the use of quality control methods.

It is important that all Sections of the Society note the dates of May 5 and 6 in their Section calendars and take steps to avoid any conflicts in program during those days, so that as many members as possible may be together for the Boston Convention.

FORTHCOMING PAPERS

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The first edition of this well-known, widely used text was developed in the early years of the Second World War for use in special classes for war production workers, and in terms of the concept of production control at the beginning of that period.

Now the book has been extensively revised in terms of (1) the current concept of production control in industrial organizations, and (2) the needs of a collegiate program of management of engineering.

Throughout, production control is regarded as part of an integrated series of controls, and as based on other controls such as product design, methods, quality, and procurement. Thus the focal emphasis is on the specific functions in production control. However, in accordance with the current trend of inter-relationship of control, each of the other closely related controls is considered for clarity of interpretation.

The general method of presentation has been: (1) Statement of basic principles; (2) Illustration of principles through application to specific industrial situations; (3) Case problems taken from industrial experience, to which the student applies the specific principles involved. The number of case problems has been considerably increased, and in all instances reflect postwar experiences.

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